

Bond University

DOCTORAL THESIS

Musculoskeletal and physiological profile of elite and recreational surfers: injuries and sports specific screening

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MUSCULOSKELETAL AND PHYSIOLOGICAL PROFILE OF ELITE AND RECREATIONAL SURFERS: INJURIES AND SPORTS SPECIFIC SCREENING

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A thesis submitted to Bond University in fulfilment of the requirements for the degree
of Doctor of Philosophy (PhD)

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ABBREVIATIONS

Abbreviations used Throughout This Thesis

DEXA	Dual Energy X-ray Absorptiometry
DF	Dorsiflexion
ER	External Rotation
HHD	Hand-Held Dynamometer
HPC	High Performance Centre
hr	Hour
IR	Internal Rotation
min	Minute
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
ROM	Range of Motion
s	Second
VO _{2max}	Maximum Oxygen Consumption Value
VO _{2peak}	Peak Oxygen Consumption Value
vs.	Versus
WCT	World Championship Tour
WQS	World Qualifying Series

Units of Measurement

cm	Centimetre
kg	Kilogram
L	Litre
m	Meter

ml	Millilitre
mmol	Millimole
N	Newtons
W	Watt

Statistical Abbreviations and Symbols

CI	Confidence Interval
ICC	Intra class Correlation Coefficient
<i>U</i>	Mann Whitney U Test
<i>M</i>	Mean
<i>N</i>	Total Sample
<i>n</i>	Sub-Sample
<i>p</i>	Probability Value
<i>r</i>	Pearson Product-Moment Correlation Coefficient
<i>r</i> ²	Coefficient of Determination; measure of strength of relationship
<i>r</i> _s	Spearman Rank Order Correlation
<i>SD</i>	Standard Deviation
<i>SEM</i>	Standard Error of Measurement
<i>SRD</i>	Smallest Real Difference
<i>t</i>	T-test Statistic
χ^2	Chi-Square Test Statistic

DECLARATION OF AUTHORSHIP

“This thesis is submitted to Bond University in fulfilment of the requirements of the degree of Doctor of Philosophy (PhD). This document represents my own original work towards this degree and contains no material which has been previously submitted for a degree or diploma at this University or any other institution, except where due acknowledgement is made”.

DECLARATION OF AUTHOR CONTRIBUTION

All the co-authors on the papers indicated in the following table have approved these works for inclusion in James Furness's doctoral thesis

Furness, J. , Hing, W., Walsh, J., Abbott, A., Sheppard, J. M., & Climstein, M. (2015). Acute injuries in recreational and competitive surfers: incidence, severity, location, type, and mechanism. <i>The American Journal of Sports Medicine</i> , 43(5), 1246-1254.	JF 80%, WH 5%, MC 7%, AA 5%, JS 3%.
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RESEARCH OUTPUTS ARISING FROM THIS THESIS

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Furness, J., Hing, W. A., Abbott, A., Walsh, J., Sheppard, J. M., & Climstein, M. (2014). Retrospective analysis of chronic injuries in recreational and competitive surfers: injury location, type, and mechanism. *International Journal of Aquatic Research and Education*, 8(3), 277-287. doi: 10.1123/ijare.2013-0032

Furness, J., Hing, W., Abbott, A., Climstein, M., & Johnstone, S. (2015). Assessment of shoulder range of motion in prone versus supine: a reliability and concurrent validity study. *Physiotherapy Theory and Practice*, 31 (7), 489-495. doi: 10.3109/09593985.2015.1027070.

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This project was always about combining my two passions in life, surfing and physiotherapy. I always remember a conversation I had with a patient of mine a few years back. I asked him what the key to happiness was; his reply, "You need to make your passion your work". Three and a half years have flown by mainly because I have done that very thing.

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disabled teen in a bid to save him. This display of love and bravery will forever resonate with me. I am sure you would be proud of this work!

ETHICAL APPROVAL

The Bond University Human Research Ethics Committee (RO 1540 and RO 1610) approved two ethics applications. Copies of ethical approval and informed consent forms are found in Appendix 1.

ABSTRACT

It is well known that physical activity and sport participation can have a positive effect on an individual's physical and psychological status. This is in-line with the current priorities of the World Health Organisation, which are to increase activity, nutrition and healthy living. However, along with the positive effects of sport participation it can often result in injury. Severe or poorly rehabilitated musculoskeletal conditions can often result in long-term degenerative changes leading to disability. Musculoskeletal conditions result in the third highest cause of disability in the world and the highest cause of disability within Australasia. More recently a trend has grown towards screening athletes; musculoskeletal, biomechanical, physiological and general health. These measures are taken to provide a profile, identify strengths and weaknesses, and provide recommendations to both prevent future injury and or improve performance. To our knowledge, no surf specific screening tool exists in the sport of surfing. Although surfing is currently practiced world-wide with an estimated 37 million surfers, scientific research has been severely neglected.

The general aim of this thesis was "To create a screening tool encompassing specific musculoskeletal and physiological tests to be utilised in a surfing population". Therefore, an understanding of injury in the sport of surfing was needed to guide the direction of the surf specific screen. An initial literature review conducted around injury epidemiology and data collection methods highlighted the need to capture new information outside of hospital environments. Consequently, a survey (Study 1) was developed; the findings of which identified the shoulder and lumbar spine as key injury prone locations.

Understanding injury epidemiology in the sport of surfing was foundational in this research project. The next step was to physically screen a surfing cohort. Exploration of current screening techniques was needed to aid in developing a surf specific screen. A literature review identified established methodologies for physiological assessment; however there were minimal surf specific musculoskeletal studies. Several objective tests for the key injury prone locations were selected based on whether they were specific to surfing and shown to be reliable. The literature review however highlighted the lack of methods to assess the thoracic spine and the shoulder in a prone position.

Study 2 was therefore designed to determine the reliability of two new assessment methods for the shoulder and thoracic spine. It was determined following reliability

analysis that prone shoulder assessment was a reliable and sport specific method to assess a surfer's shoulder. A surf specific test was also designed to determine thoracic mobility in the sagittal plane. This method assessed the movement change from T1-T12 by subtracting the value scored from maximal extension from the value scored from maximal flexion; reliability analysis revealed excellent ICC values.

The final aspect of this thesis involved the implementation of the surf specific screen (Study 3). The musculoskeletal and physiological profile of both a competitive and recreational surfer was presented. Several discrepancies in ROM are apparent between both cohorts (thoracic rotation, lumbar extension, hip internal rotation and ankle dorsiflexion) and when comparing the current study's findings with previous research. This baseline data provides ROM and strength guidelines for both recreational and competitive cohorts. Longitudinal studies are needed to determine which tests may be predictors of future injuries.

The physiological profile of competitive and recreational surfers was also presented. Key performance variables ($\text{VO}_{2\text{peak}}$, peak and relative power output) were significantly higher in competitive surfers indicating this is both an adaptation and requirement in this cohort. Arm span and ape index were the anthropometric measurements that were significantly greater in the competitive group; whether this is a result of training effect or a physical predisposition is yet to be determined. This information provides insight into adaptations associated surfing subgroups and direction for clinicians dealing with these athletes.

In conclusion, this thesis provides clinicians with a surf specific screen which involves a series of reliable and surf specific physiological and musculoskeletal assessment techniques to be used individually or together. Clinicians dealing with surfers are able to utilise these results to compare against the current surfer they are treating. These findings can be used to assist with rehabilitative goals and/ or direct conditioning exercises, prevent injuries and potentially enhance performance.

THESIS STRUCTURE

This research is centred on three distinct areas specific to surfing; injury epidemiology, surf specific screening and profiling. This thesis has a unique structure; where by a literature review is presented prior to individual studies. The subsequent results from each study are presented in six papers throughout this thesis.

Chapter 1 addresses injury epidemiology and presents a literature review and Study 1. The results of Study 1 are presented in two published papers.

Chapter 2 addresses surf specific screening. The chapter provides a general review of screening methods specific to surfing. It then presents two specific literature reviews of shoulder and thoracic assessment. As a result of the reviewed literature Study 2 involves two reliability papers.

Chapter 3 addresses profiling of recreational and competitive surfers. The screening measures identified in Chapter 2 are implemented in a surfing cohort. Therefore, this chapter presents Study 3 in the form of two papers. The first paper presents the musculoskeletal profile and the second paper presents the physiological profile of recreational and competitive surfers.

Chapter 4 then summarises the key findings from each individual chapter, presents study limitations, clinical applications and further directions for research. Finally, the thesis conclusions are presented. To provide further clarity Figure 1 presents an illustration of the overview of the thesis.

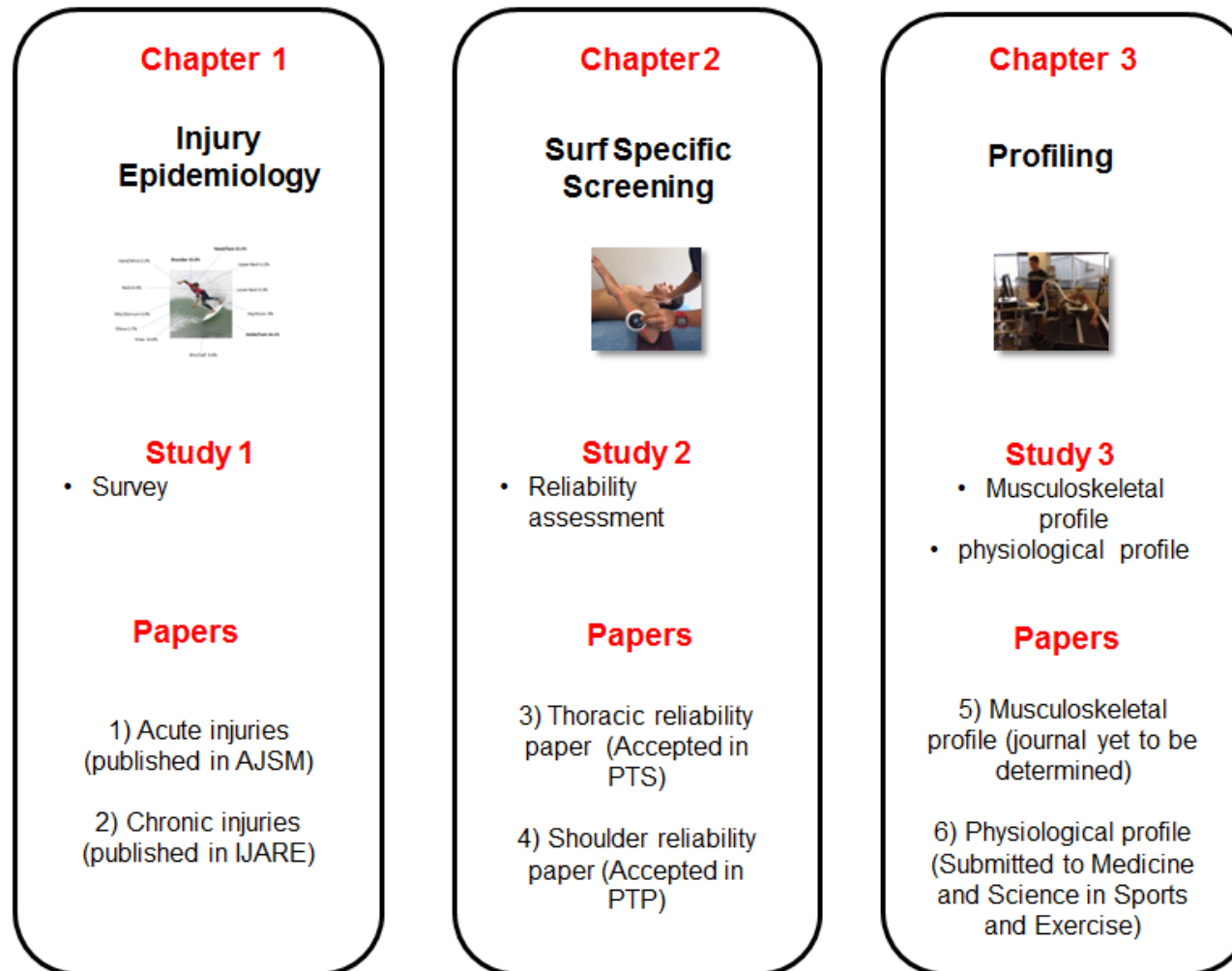


Figure 1: Illustration of Thesis Overview

THESIS RATIONALE

Surfing is both a recreational and competitive sport practiced globally and within Australia. In comparison to most mainstream sports there appears to be a paucity of research in the area of surfing. The limited research has predominantly focussed around physiological testing and injury epidemiology. To our knowledge there is minimal research performed around surf specific screening and subsequent profiling at both competitive and recreational levels.

A surf specific screen implemented in a surfing cohort would essentially provide three main outcomes. Firstly an overall profile of both a recreational and competitive surfer would be attained. This will allow for identification of adaptations (positive or negative) as a result of participating in surfing. Secondly it will provide reference data for both recreational and competitive surfers relating to musculoskeletal and physiological testing. Thirdly, it would provide information to clinicians working with this type of athlete and direct appropriate exercise prescription.

Therefore prior to designing a surf specific screen, key information around injury specific to surfing needed to be attained (addressed in Chapter 1 and Study 1). In conjunction with understanding injury in the sport of surfing, specific and reliable assessment techniques needed to be selected to include in the surf specific screen. To do this previous assessment methods in the sport of surfing needed to be explored and evaluated (addressed in Chapter 2 and Study 2). Finally, by implementing a surf specific screen in a surfing cohort the above outcomes are achieved (addressed in Chapter 3 and Study 3). Therefore, this rationale provided the foundation for the Thesis Aims below.

Thesis Aim

To create a screening tool encompassing specific musculoskeletal and physiological tests to be utilised in a surfing population.

Specific Aims

The specific aims in relation to the first three chapters are presented below.

- Chapter 1: To provide epidemiological data regarding injury incidence, location, type and mechanism for acute and chronic injuries in recreational and competitive surfers

- Chapter 2: To design a surf specific screen incorporating reliable and specific methods for a surfing population
- Chapter 3: To provide a comprehensive musculoskeletal and physiological profile of a recreational and competitive surfer

CHAPTER 1: INJURY EPIDEMIOLOGY

1.0.1. Preface

This chapter is divided into three distinct sections. Firstly, a literature review presents the results of previous surf specific epidemiological studies. The second section of this review then identifies the methodologies utilized within these studies. Study 1 itself is then presented with the results of this study presented in two published papers. Figure 2 provides an illustration of the outline of Chapter 1.

Material within this chapter relates to a specific aim of this thesis; “To provide epidemiological data regarding injury incidence, location, type and mechanism for acute and chronic injuries in recreational and competitive surfers”.

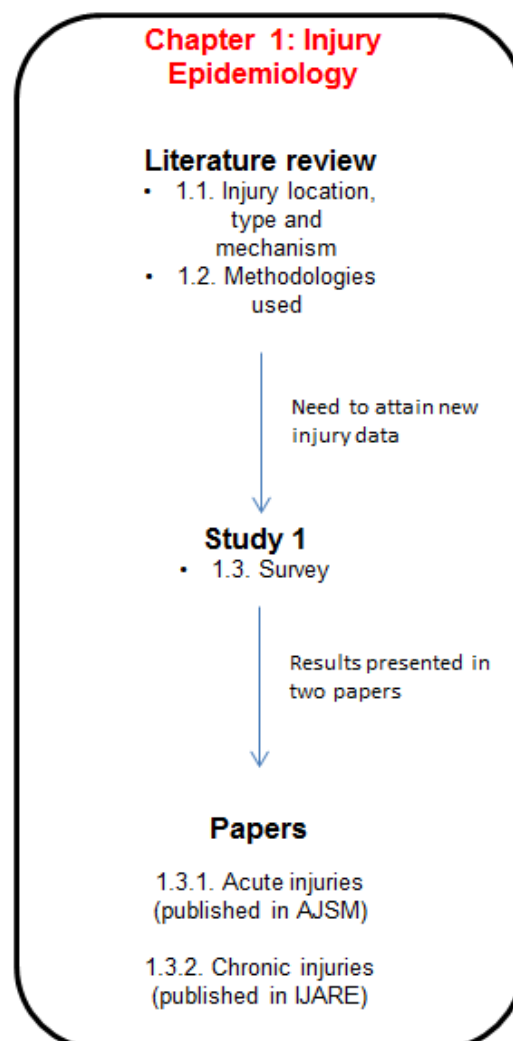


Figure 2: Outline of Chapter 1

1.1. SURFING INJURIES; LOCATION, INCIDENCE, TYPE, MECHANISM AND RISK FACTORS

1.1.1. Introduction

The basic physiological requirement and skill of surfing has remained unchanged for over 1,000 years - a surfer paddles a board out to the waves and rides it back to shore (Moser, 2008; O'Rourke, 2006). The sport can be further broken down into periods of repetitive upper body movement during paddling and prolonged periods of sitting, interspersed with intermittent explosive lower body and trunk movements (Mendez-Villanueva & Bishop, 2005).

There are estimated to be over 37 million surfers worldwide (Moran & Webber, 2013) and 2.5 million recreational surfers within Australia (Stark, 2010) . The recreational activity and sport of surfing has grown dramatically since the 1960's due to surfing sponsors and associations, however the scientific research has been poorly mirrored in comparison to most other mainstream sports. Surfing is an extreme sport that is associated with significant benefits but also carries a significant risk of physical injury.

It is well know that training for and participating within a sport will result in physiological adaptations that result in positive changes in both flexibility and strength. An overwhelming amount of evidence has shown that regular physical activity has important and wide ranging health benefits, ranging from reduced chronic diseases such as heart disease, Type 2 diabetes and some cancers (Heggie & Caine, 2012). However participating in sport can lead also to negative adaptations, creating ipsilateral and contralateral strength and flexibility imbalances and therefore increasing the risk of developing an injury which can result in pain and reduced function (Probst, Fletcher, & Seelig, 2007).

The purpose of this review was to comprehensively present the research to date around acute and chronic injury in the sport of surfing. More specifically, injury type, location, mechanism, risk factors, injury definitions, incidence and methodologies used to attain injury specific data.

1.1.2. Methods

Literature utilized in this review was attained through a database search using Pubmed, EMBASE, CINAHL, and SPORT-Discuss. The search was limited to articles involving human participants published in English language prior to March 2014. Article titles and their abstracts were screened for relevance and the bibliographies of key articles were reviewed to identify any further relevant articles. Articles were deemed relevant if they presented data specific to either acute or chronic injuries occurred as a result of surfing. The purpose of this narrative review was to review information regarding injury epidemiology and the data collection methods used.

Analysing the research solely around surfing injuries proves to be difficult due to variations in research methodologies between studies. The significant information that needs to be gained is where the injury occurs (anatomical location); the stage of injury (acute or chronic); the types of injuries occurring (lacerations, sprains etc.); and the mechanism of injury for that site. The majority of surf-related studies currently available present these factors (injury location, type and mechanism) independently of each other and therefore it is difficult to gain further insight from the data collected. Where possible literature will be presented which combines these factors. The methodological aspects and parameters used (data collection methods, injury definitions, injury rates) within the relevant studies needs to also be reviewed. However, for clarity this will be presented in the second half of the review.

1.1.3. Discussion

1.1.3.1. Injury Type

1.1.3.1.1. Acute Musculoskeletal Injuries

Acute injury is defined as a sudden onset of sharp pain or sudden impact that the person can relate to a specific situation, normally resulting in tissue damage in a localised region (Askling, Lund, Saartok, & Thorstensson, 2002). Table 1 reveals the types of injuries identified in the reviewed literature concerning surfing. It includes the percentages of each acute injury and therefore only includes articles where this data was available. In general, lacerations and soft tissue injuries (sprains and strains) were the most common forms of injury identified. It needs to be noted, that each

study differs in the method of data collection and the injury definition used; therefore caution should be applied when directly comparing studies.

In an early study conducted by Lowdon, Pateman, and Pitman (1983) lacerations accounted for 40% of all reported surfing injuries that resulted in time lost surfing or that required medical attention. Similar findings were presented by Kennedy, Vanderfield, and Huntley (1975) who found that 69% of all injuries reported were superficial cuts or bruises. Survey results from an Accident and Emergency clinic in Byron Bay revealed 80% of all surfing injuries were lacerations mainly to the head (Roger, 2002). Conversely results from online survey's by Nathanson, Haynes, and Galanis (2002), Taylor, Bennett, Carter, Garewal, and Finch (2004) and (Meir, Zhou, Gilleard, & Coutts, 2011) show lower numbers of lacerations accounting for 42%, 46.4% and 28% respectively of all significant surfing injuries. When considering competitive surfers the percentages are even less as reported in the study conducted by Nathanson, Bird, Dao, and Tam-Sing (2007) who found lacerations comprising only 30% of all surf related injuries which require medical attention.

Results clearly differ if data collection occurs in accident and emergency clinics as most soft tissue injuries are likely to be treated elsewhere or not at all. The decrease in the percentage of lacerations over time are possibly due to changes in board design, introduction of surf equipment (leashes and nose guards) and the increase in other forms of injury (such as soft tissue sprains and strains). The reduction in lacerations in competitive surfers compared to recreational surfers is possibly due to increased awareness of the external environment and introduction of more soft tissue injuries.

Since the commencement of surfing injury research, soft tissue sprains and strains have been steadily rising as board design changes have allowed for more aggressive turning manoeuvres and more recently aerial manoeuvres. Initial research by Barry, Kleinig, and Brophy (1982) found that soft tissue sprains and strains accounted for less than 10% of all surfing injuries recorded in recreational surfers. Nathanson et al. (2002) reported sprains and strains accounted for 12% of all acute injury. More recent studies have shown a rise in soft tissue sprains and strains, comprising of almost half the total percentage of all injuries (Nathanson et al., 2007; Taylor et al., 2004).

It is important to note that the frequency of soft tissue sprains and strains have been influenced by where the data collection took place (e.g., Emergency Departments, survey based or on site recording). More recently studies which have analysed competitive surfers have revealed a trend towards greater frequencies of soft tissue

sprains and strains. Only two studies have analysed injury solely in competitive surfing. Nathanson et al. (2007) performed a prospective study on competitive surfers and found that soft tissue sprains and strains were the most common form of injury accounting for 39% of all injuries. A much earlier survey based study on international competitive surfers found that soft tissue injuries accounted for 35% of all injuries (Lowdon, Pitman, Pateman, & Kenneth, 1987).

Table 1: Acute Injuries in Recreational and Competitive Surfers

Author	TYPE OF INJURY (%)							
	Abrasion	Concussion	Contusion	Dislocation	Fracture	Laceration	Sprain/strain	Other
Hospital or ED data								
Roger, 2002	-	-	2	2	10	80	2	4
Taylor, et al., 2004	-	-	-	2.2	14.2	47.2	12.4	24
Prospective data (competitive surfers)								
Nathanson, et al., 2002	5	-	9	9	-	30	39	8
Survey participants (competitive surfers)								
Lowdon, et al., 1987	-	-	4	2	9	45	37	3
Survey Participants (recreational surfers)								
Meir, et al., 2011	-	-	-	6.5	11.3	18.9	63.3*	
Taylor, et al., 2002	-	-	-	10.7	8.9	46.4	28.6	5.4
Nathanson, et al., 2002	-	6	13	-	8	42	12	19

(-) No data was available from the study. * Sprains, strains and other forms of injury were combined

1.1.3.1.2. Chronic Musculoskeletal Injuries

Chronic injury is often defined as persistent or episodic pain lasting more than three months (Jordan, Holden, Mason, & Foster, 2010). It can be a gradual onset of pain with no definitive mechanism of injury, or the result of an acute injury poorly rehabilitated with residual symptoms (Pinzon & Larrabee, 2006). A study conducted by Nathanson et al. (2002) identified that 50% of all chronic injuries were classified as an overuse syndrome involving the musculoskeletal system. Nathanson et al. (2002); Taylor et al. (2004) revealed similar results with nearly half of all chronic injuries reported having some form of musculoskeletal origin. Survey based data collection methods were used in both studies and the exact type of chronic injury was identified as either an overuse syndrome or a chronic injury of musculoskeletal origin. Both of these studies broadly categorise chronic injury, whereby the type of injury (nerve, joint or muscular) was not identified. These studies have been displayed in Table 2.

1.1.3.1.3. Chronic Non-Musculoskeletal Injuries

With participation only possible in the water, surfers can be prone to injuries as a result of long term environmental exposure. These chronic injuries commonly involve the ear, eyes and skin. Auditory exostoses (surfers ear) is a chronic ear condition where bony outgrowths begin in the temporal bone and protrude into the ear canal (Taylor, Zoltan, & Achar, 2006). It is generally accepted that the aetiology is thought to be from cold water exposure (less than 18.5 degrees C) and increased levels of participation in water based/surfing activities (Taylor et al., 2006), however this is not conclusively proven. Wong et al. (1999) examined the otoscopic findings of 307 surfers and reported that the presence and severity of auditory exostoses was directly correlated with time spent surfing. Otitis externa (swimmer's ear) is another form of ear pathology caused from long-term water exposure (stagnant water within the external auditory canal). Trauma to the epithelial lining within the ear canal and external exostoses can also predispose surfers to otitis externa. Taylor et al. (2004) found that 45.9% of chronic health problems reported was associated to the ear, which included chronic recurrent otitis externa and or ear canal exostoses. Nathanson et al. (2002) reported lower rates of ear pathology; auditory exostoses and otitis externa represented 7 and 14% of the total number of chronic injuries respectively.

Prolonged sun exposure through surfing can also result in both eye and skin conditions. Pterygium is an eye condition which involves a benign growth of clear skin over the cornea. This is a protective mechanism as a result of long term sun exposure. Two studies have identified this pathology among recreational surfers, with the prevalence found to be low in regards to total chronic injuries (Nathanson et al., 2002; Taylor et al., 2004).

Table 2: Chronic Musculoskeletal and Non-Musculoskeletal Injuries

		Nathanson et al., 2002	Taylor et al., 2004
Type of Chronic Injury	Location	Percentage (%)	Percentage (%)
Overuse syndromes			
Strain	Shoulder	18	10.3
	Back	16	19.9
	Neck	9	
	Knee	9	8.2
	Elbow	5	0.7
Inflammation	Rib	3	-
Other (joint, muscle pain)	Unspecific	-	9.6
Environmental Exposure			
Exostosis	Ear	14	45.8
Otitis	Ear	7	
Sinusitis	Nose	2	0.7
Cellulitis	Skin	6	-
Pterygium	Eye	4	4.8
Other	Unspecific	7	-
Total		100	100

1.1.3.2. Mechanism of Injury

Identifying the mechanism or contributing factors to injury is crucial when investigating injury epidemiology. Only two studies have identified direct relationships between mechanism, injury location and the type of injury (Lowdon et al., 1983; Lowdon et al., 1987). Both studies identified that being struck by the surfer's own board, another surfer's board or striking the sea floor resulted in lacerations or fractures mainly to the head region; injury caused through stress from a specific surfing manoeuvre resulted in sprains and strains in the lower back, knee and ankle regions; injury caused from repetitive paddling resulted in sprains and strains mainly in the shoulder region (Lowdon et al., 1983; Lowdon et al., 1987).

Several studies failed to show the relationship between mechanism, type and location of injury, suggesting that injury was mainly caused through trauma (Allen, Eiseman, Straehley, & Orloff, 1977; Barry et al., 1982). A study conducted by Roger (2002) identified that the mechanism of all injuries was either from direct contact from the surfers own board, someone else's board or contact with the ocean floor. All of these mechanisms of injury are a result of direct contact; it seems surprising that no non-contact mechanisms (i.e., twisting or performing a manoeuvre) were identified.

Interestingly no study identified mechanisms or aggravating factors which contributed to chronic injury. The two studies which reviewed chronic injury in surfing suggested that shoulder overuse injuries were a result of repetitive paddling and ear and eye conditions are a result of environmental exposure (Nathanson et al., 2002; Taylor et al., 2004).

1.1.3.3. Anatomical Location of Injuries

Table 3 attempts to analyse the anatomical distribution of surfing injuries, however due to discrepancies between definitions of body parts, global body regions were used within the table. Studies that did not report injuries by anatomical location were excluded from the table.

1.1.3.3.1. Head and Face

Table 3 reveals that both the head and lower limbs are the most common regions for acute surfing injuries. Further investigations into the location of injury reveal the majority of head and face injuries are a result of a laceration predominantly due to direct trauma from either the surfers own board, contact with another surfer's board or contact with the sea floor (Nathanson et al., 2002; Taylor et al., 2004). It is also evident that there is an increase in reported head injuries when data is collected out of Emergency and Hospital environments (Allen et al., 1977; Barry et al., 1982; Roger, 2002) compared to survey based studies (Meir, Zhou, Gilleard, & Coutts, 2012; Nathanson et al., 2002).

Table 3 also reveals high percentages of chronic injuries in the head and face region; however most of these injuries are of non-musculoskeletal origin. As previously discussed both the ear and eyes are prone to chronic injury due to long term water and sun exposure.

1.1.3.3.2. Lower Extremity

When further analysing the distribution of lower limb injuries the knee and ankle appear to represent a high proportion of the total number of injuries. A recent study by Meir et al. (2011) revealed the knee and ankle represented 15.9% and 14.9% of all injuries respectively. It has been theorized through video and photographic evidence that rear knee valgus stress may contribute to knee injuries (Everline, 2007), however no study to date has identified whether or not there is a higher incidence of injury in the rear leg compared to the front leg. The introduction of aeriels and radical manoeuvres in recent years may also contribute to an increase in lower limb injuries. A prospective study conducted on competitive surfers revealed nearly half of all injuries originated from the lower limb (Nathanson et al., 2007). This study also revealed that the most common type of injuries were knee sprains and strains accounting for 19% of the total number of injuries. The majority of these knee injuries were a result of aggressive turning manoeuvres or aeriels. It is therefore hypothesised that these movements are thought to place high stresses on the knee joints (Everline, 2007).

1.1.3.3.3. Upper Extremity

Acute upper extremity injuries generally represent lower percentages as compared to the other regions analysed. However a more recent study conducted on surfing related injuries reported higher percentages of upper extremity injuries, with the shoulder representing 13.1% of all injuries (Meir et al., 2012) . Nathanson et al. (2002) found that upper extremity injuries involved 12.1% of the total injuries; however 35% of these injuries were located in the shoulder.

When reviewing the studies which included chronic musculoskeletal injury, the upper extremities represented higher percentages of injuries in contrast to lower limb and head injuries. Nathanson et al. (2002) revealed that shoulder injuries represented 18% of all chronic injuries. Although this study did not include the mechanism of injury or the aggravating factors, assumptions have been made that the causes are due to the repetitive nature of paddling and the overuse of the shoulder muscles (Everline, 2007). It has also been hypothesized that with the reduction in board size there is less floatation leading to a higher elbow elevation during paddling, hence, greater impingement on the rotator cuff muscle group (Barry et al., 1982).

1.1.3.3.4. Spine/ Trunk

Table 3 shows that acute spine/trunk injuries represent lower percentages of the total number of injuries than the head/face and lower extremity regions. However the most recent study conducted reviewing surf related injuries revealed higher percentages of acute injuries located in the torso and spinal column. Surfing can be interspersed with long periods of sitting or paddling followed by intermittent periods of wave riding where aggressive upright surfing manoeuvres are performed (Lowdon et al., 1983). These manoeuvres involve rotation of the thoracic and lumbar spine and have been suggested as a possible mechanism of acute spinal injury (Meir et al., 2012). Prolonged periods in the prone position with the trunk hyperextended during paddling have also been reported as a potential mechanism of acute spinal injury (Lowdon et al., 1983; Taylor et al., 2004). The recent increase in acute spinal injuries may also be attributed to decreases in board size, which are allowing more radical manoeuvres to be performed (Everline, 2007).

When reviewing chronic musculoskeletal injuries the spine represented nearly 20% of the total number of chronic injuries (Nathanson et al., 2002; Taylor et al., 2004).

Neither study obtained data on the mechanisms of chronic injury in the spine however; the long-term effects of hyperextension occurring in the vertebral column during paddling have been suggested as a possible cause (Everline, 2007). At this stage, no study has determined the mechanisms associated with chronic injury, and therefore it is difficult to draw thorough conclusions.

Table 3: Anatomical Location of Acute and Chronic Surfing Injuries

Type of Surfer	Author	Stage of Injury	Anatomical Distribution of Injury (%)*			
			Head/face	Spine/trunk	Upper Extremity	Lower Extremity
Competitive Surfers	Nathanson, et al., 2007	Acute	25	11.2	25.0	38.8
Recreational Surfers	Meir, et al., 2011	Acute	12.8	21.8	20	39.8
	Taylor et al., 2004	Acute	26.2	15.5	12.5	45.8
		ED	42	9.7	16.1	22.8
		Chronic	51.4	19.9	11.0	8.2
	Nathanson, et al., 2007	Acute	37.1	13.2	12.7	37.0
		Chronic	36.0	19.0	23.0	9.0
	Barry, et al., 1982	Acute	22.0	17.5	21.5	36.4
Average % for Acute Injuries			28.3	15.3	18.5	37.9
Average % for Chronic Injuries			49.2	21.9	19.2	9.7

*Anatomical distributions involve multiple locations; spine/trunk refers to injuries in any spinal region, torso and rib region; upper extremity refers to shoulder, elbow, wrist and hand; lower extremity refers to hip, knee, ankle and foot.

1.1.3.4. Risk Factors

The literature reviewed has identified several risk factors that increase the chance of significant or major injury. Nathanson et al. (2002) revealed that older surfers (above 40 years old), competitive surfers and those surfing larger waves (overhead or higher) are at significantly greater risk of major injury (this refers to an injury which resulted in time off work, surfing or required medical treatment). Nathanson et al. (2007) identified that as the duration of a surfing session increased so did the chance of significant injury. Additionally the number of surfing injuries increases as frequency and duration of surfing sessions increases (Taylor et al., 2004). Meir et al. (2011) revealed that the number of hours surfed per week exceeded the World Health Organisation's (WHO's) recommendation of regular exercise. The authors suggested that the excessive hours spent surfing may be contributing to overuse type injuries.

1.1.3.5. Challenges in Summarising Surf Specific Injury Epidemiology

Comprehensively summarising injury stage, type, location and mechanism proves to be difficult due to four main reasons. 1) limited number of surf specific epidemiological studies; 2) differences in study design (prospective, retrospective); 3) differences in terminology for anatomical location, type and mechanism; and 4) differences in data collection locations (for example Emergency Departments compared to online surveys); 5) injury location, type and mechanism are often reported independently of each other.

These difficulties should be considered when providing summaries of injury epidemiology in the sport of surfing; especially when drawing comparisons between studies.

1.2. STUDY DESIGN AND INJURY DEFINITIONS IN EPIDEMIOLOGICAL RESEARCH

When reviewing the methodologies used around injury it is crucial to review how data was collected, the way injury was defined, and the denominator used to calculate injury rate or risk (Goldberg, Moroz, Smith, & Ganley, 2007). In this approach, key methodological flaws can be noted and avoided for future research. Table 4 illustrates comparisons between data collection methods, injury definitions and injury rates.

1.2.1. Assessment of Study Designs Within the Literature

Research around surfing injury has used a range of data collection methods including retrospective data collection through face to face questionnaires; online surveys, accessing administrative data in hospital and emergency department settings and prospectively through onsite medical personnel. It is evident that results differ between data collection methods. For example, Roger (2002) collected injury data from hospital and medical clinics and found that the majority of surf related injuries were lacerations compared with Nathanson et al. (2007) who gathered prospective data at surfing contests worldwide and found higher percentages of sprains and strains.

1.2.1.1. Online Surveys

The introduction of the internet has allowed for more innovative ways of data collection and this has been evident with the use of online surveys. With high numbers of recreational participants located coastally the internet provides an opportunity for a wider range and number of both recreational and competitive surfers to participate (Meir et al., 2011).

A key limitation of this data collection method is it limits participation for non-internet users. This poses the threat that a true representation of the surfing population is not reflected, as not all surfers have access to the internet. Throughout this literature search, only two online surveys were identified (Meir et al., 2011; Nathanson et al., 2002). Both studies revealed differing results to previous studies conducted in

hospital and medical settings (Allen et al., 1977; Barry et al., 1982; Kennedy et al., 1975; Roger, 2002; Roger & Lloyd, 2006) with lower numbers of lacerations and traumatic injuries and higher numbers of soft tissue sprains and strains. A clear weakness of online surveys as with any retrospective study is that the participant must be able to accurately recall the event. Research has illustrated that as time passes since the injury the ability to recall decreases (Jenkins, Earle-Richardson, Slingerland, & May, 2002). In order to reduce memory decay a study conducted by Meir et al. (2011) only included acute injuries within the previous twelve months to completing the online survey. An online survey conducted by Nathanson et al. (2002) however included acute injuries within the previous five years to commencing the online survey.

Despite the weaknesses discussed above, online surveys provide significant benefits by reducing the reliance on administrative data within hospital settings and providing opportunities to gather data from a wider range of geographic locations. This also limits the bias towards more medically related injuries (Heggie & Caine, 2012). It is evident that online surveys provide an innovative way of reaching the participant as opposed to some of the previous data collection methods used.

1.2.2. Injury Definitions

Clear injury definitions allow the researcher to gather relevant information and help distinguish between major/significant and minor injuries. Injury definitions also provide parameters to determine the severity of the injury; this literature review identified that distinct injury definitions were not always implemented.

One of the earliest studies conducted on surfing injury recorded only injuries classified as “significant” and were defined as an injury which resulted in hospitalisation as a result from a surfing accident (Allen et al., 1977). Research by Lowdon et al. (1983) classified injuries as either moderate or severe and defined injuries as one which required either medical attention or days lost surfing. Roger (2002) used the classification of major or minor injuries; major injuries were those that required medical follow up or a laceration longer than seven centimetres and minor injuries were those that required no follow up. Nathanson et al. (2002) also classified injuries as either minor or significant. Minor injuries were those injuries where the surfer was able to continue surfing, whereas significant injuries were those injuries where the surfer was unable to continue surfing, work or school for more than one day, sought

medical care, or was hospitalized. Taylor et al. (2004) used a similar classification however without the incorporation of minor injuries.

The identified studies clearly used different injury definitions; it appears more appropriate that injury definitions need to incorporate both minor and major injury to limit bias towards reporting major injuries only. Significant or major injury needs to be defined as an inability to surf, work or result in receiving medical attention; this is crucial as participation in surfing may continue despite the presence of significant or major injury.

1.2.2.1. Defining Incidence of Injury

Incidence refers to the number of new occurrences of an injury during a specified time period (Rothman, Greenland, & Lash, 2008). Risks and rates are two methods of quantifying incidence. An injury report without a denominator can only describe frequencies, while a report with a denominator can provide an injury rate and risk (Heggie & Caine, 2012). Injuries can be reported as injuries per athlete or injuries per year/season or injuries per practice/game exposure or injuries per athlete-hour of exposure. As surfing sessions can vary in length it seems more relevant to determine injury rate based on hours as opposed to days spent surfing.

This literature review again identified discrepancies in how injury rate was calculated. Allen et al. (1977) calculated an injury rate from the number of hospitalisations divided by an estimated number of surfers on the beach over a 54-month period; to be one acute injury per 17,500 surfing days. Taylor et al. (2004) performed a survey that calculated an acute injury rate based on the number of injuries within the past twelve months divided by the number of days surfed (1,000 surfing days). Meir et al. (2011) quantified this further by using an online survey which gathered data on hours spent surfing. An injury rate of 3.5 acute significant injuries per 1,000 hours surfed was calculated. A study by Nathanson et al. (2007) gathered prospective data and calculated an injury rate of 6.6 acute significant injuries per 1,000 hours of competitive surfing.

Prospectively gathering injury data while recording the hours of exposure would limit the reliance on participants subjectively reporting time spent surfing. However, time constraints and accessibility make this task difficult. It is clear though that reporting

an injury rate based on hours of exposure is suitable for the sport of surfing as surfing sessions vary considerably.

Understanding injury risk (also known as Incidence Proportion) provides additional information regarding injury incidence. Injury risk refers to the number of athletes injured divided by the number of athletes exposed to the risk (Knowles, Marshall, & Guskiewicz, 2006). Injury risk is more user friendly for practitioners and coaches and allows a simple probability calculation (for example, 1 in every 2 athletes will sustain an acute injury over the season). Surprisingly very few surf specific studies commented on injury risk and tended to put more emphasis on injury rate. A study conducted by (Meir et al., 2012) was the only identified study, which reported an injury risk of 0.38 injuries per surfer per year. Essentially 1 in every 3 recreational surfers will sustain an acute injury with a 12 month period.

Table 4: Methodologies used In Epidemiological Research Specific to Surfing

Author	Study Design	Data Collection method	Sample size	Injury Classification and Definition	Number of Injuries	Acute Injury rate (per 1000 days)	Acute Injury rate (per 1000 hours)
Competitive							
Nathanson, et al., 2007	Prospective	Injuries recorded by onsite medical personnel	-	Acute "significant" injuries: Unable to continue surfing for 1 or more days, required suturing or hospitalisation, all other acute injuries were considered "minor"	89 Acute over 6.5 years	2.9 per 1000 heats	Significant: 6.6 Significant and Minor: 13
Lowdon, et al., 1987	Retrospective	Survey based study	86	Acute significant or moderate injury: required medical attention and or time lost surfing	187 Acute (over a 2 year period)	4	-
Recreational							
Meir, et al., 2011	Retrospective	Online Survey	685	Acute significant injury: Unable to continue surfing for more than 1 day	389 Acute (over a 1 year period)	-	3.5
Taylor, et al., 2004	Retrospective	Mail and face to face survey	646	Acute significant injury: Required time off work, surfing, school or required treatment Chronic injury: unrelated to acute injury	168 Acute significant 146 Chronic health problems (over a 12 month period)	2.2	1.1
Nathanson, et al., 2002	Retrospective	Online Survey	1,348	Acute "Significant" injuries: Required medical care, was unable to continue surfing, work, or school for more than one day or was hospitalized. Acute "Minor" injuries: Able to continue surfing Chronic Injuries: Gradual onset	1,237 Acute 477 Chronic (over a 4 year period)	-	-
Roger, 2002	Retrospective	Survey completed in Hospitals and local Medical Clinics	-	Acute "Major" injuries: Laceration greater than 7cm or required medical follow up. All other injuries were classified as minor	83 Acute	-	-
Allen, et al., 1977	Retrospective	Hospital records	-	Hospital admission secondary to surfing	24 Acute Hospital admissions (over 56 months)	1/17500 surfer days 0.05714 per 1,000 days (estimation)	-

1.2.3. Recommendations for Future Injury Research

This review aimed to summarize the existing literature around surf related injury. It has illustrated a variance in the classification of injury types, locations and mechanisms of injury. In addition, types of data collection and the definitions also differed and altered results. Due to the incomparable nature of the results, it proves difficult to draw sound conclusions on acute and chronic injury. Therefore, the recommendations outlined below are recommended.

- Injuries need to be clearly defined and include both major and minor injuries. The stage of the injury needs to be addressed (acute or chronic) and the type of injury needs to be categorized (e.g., joint, muscular, nerve, bone, or skin related).
- There is a need for up to date information on acute and chronic injury location, type, and mechanism.
- A large sample size of recreational and competitive surfers is needed. This sample size should be large enough to represent the 2.5 million surfer's nation-wide.
- When calculating an injury rate, a dominator using hours surfed is most appropriate. This allows for a more accurate injury rate to be calculated as surf sessions can vary in duration. Injury risk or incidence proportion should also be calculated.
- Research to date has identified that age, wave size and competitive status are risk factors for injury. It has not been identified whether manoeuvres performed such as aerials put the surfer at more risk of injury. It could be assumed that the introduction of aerials and more radical manoeuvres may contribute to an increase in lower limb injuries. Whether or not there is a higher incidence of injury in the front or back leg needs to also be assessed.
- With the growing number of acute soft tissue sprains and strains reported and the absence of up to date research on chronic surfing injury it could be assumed that the number of current chronic soft tissue injuries would be

following a similar pattern. Further research into the specifics of chronic injury associated with surfing is clearly needed.

- Retrospective information initially gained on chronic injury would be integral in the development of prevention strategies and be a catalyst for further investigation.

1.2.4. Conclusion

This review has comprehensively presented the research to date around acute and chronic injury in the sport of surfing. More specifically, injury type, location, mechanism, risk factors, injury definitions, incidence and methodologies used to attain injury specific data. The review has resulted in several recommendations for future research, in particular highlighting the need to capture new injury related data specific to surfers. From the reviewed material an online survey would be the most effective approach, considering the accessibility to the internet and the coastal location of surfers. .

1.3. STUDY 1: SURVEY

Study 1 was implemented following the literature review. This study received ethics approval from the Bond University Ethics Committee (see Appendix 1). The study involved an online survey focussing on acute and chronic injuries in the sport of surfing. An illustration of the dispersion of the survey is seen in Figure 3. A copy of the actual survey is found in Appendix 2. Results from this study are presented in the form of two published papers. Section 1.3.1 presents the acute injury paper and section 1.3.2 presents the chronic injury paper.

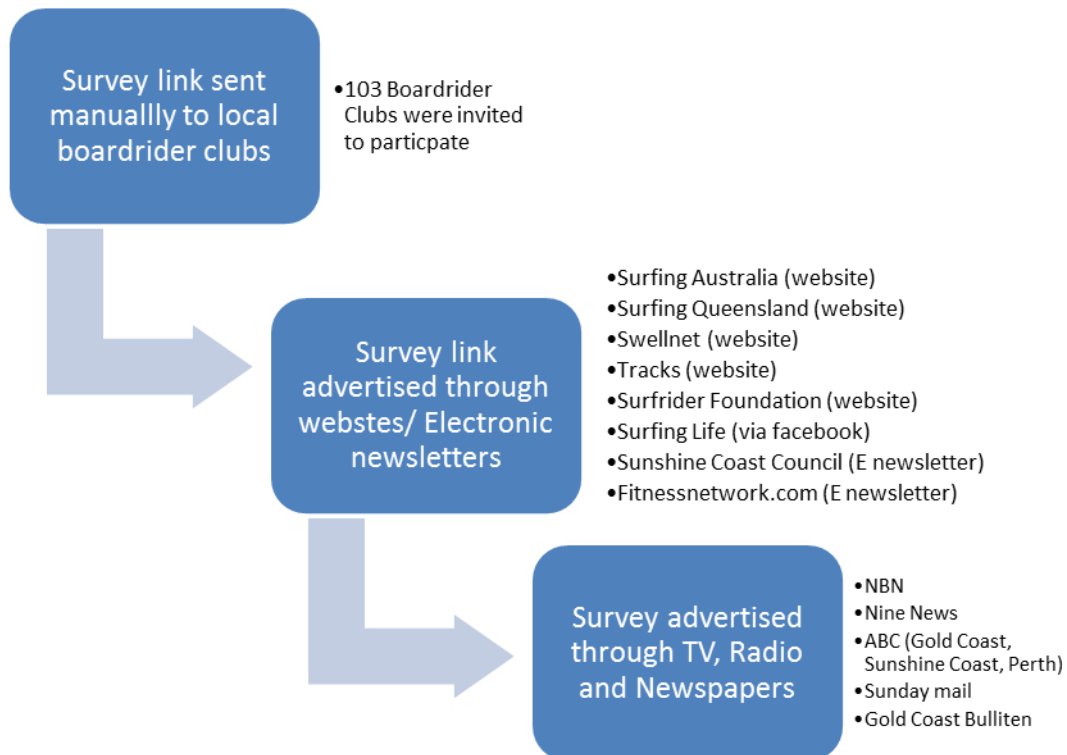


Figure 3: Delivery Methods of the Online Survey

1.3.1. ACUTE INJURIES IN RECREATIONAL AND COMPETITIVE SURFERS; INCIDENCE, SEVERITY, LOCATION, TYPE AND MECHANISM

The results of Study 1 for acute injuries are presented in the following paper. This is an Accepted Manuscript of an article published by SAGE Publications in the American Journal of Sports Medicine on February 2, 2015, available online: <http://www.sagepublications.com>; DOI: 10.1177/0363546514567062.

Furness, J., Hing, W., Walsh, J., Abbott, A., Sheppard, J. M., & Climstein, M. (2015). Acute injuries in recreational and competitive surfers: incidence, severity, location, type, and mechanism. *The American Journal of Sports Medicine*, 43(5), 1246-1254.

1.3.1.1. Abstract

Background: There are an estimated 37 million surfers worldwide with 2.5 million recreational surfers within Australia. The recreational activity and sport of surfing has grown dramatically since the 1960's, however scientific research has been poorly mirrored in comparison to most other mainstream sports. Purpose: The aim of this study was to identify the incidence, severity, location, type and mechanism of acute injuries in recreational and competitive surfers over a 12 month period. Study Design: Descriptive epidemiology study. Methods: An on-line survey using an open-source survey application was utilized. The survey consisted of two primary sections. Section one included demographic information and participation levels (age, height, weight, hours surfed, competitive level). Section two and also incorporated injury type, mechanism, severity and injury management. Results: A total of 1,348 participants (91.3% males, 43.1% competitive surfers) were included in data analysis. A total of 512 acute injuries were classified as major providing an incidence proportion of 0.38 (CI; 0.35-0.41) acute injuries per year. Incidence rate was calculated to be 1.79 (CI; 1.67-1.92) major injuries per 1000 hours of surfing. The shoulder, ankle and head/face regions had the highest frequencies of acute injury representing 16.4%, 14.6% and 13.3% respectively. Injuries were predominantly of muscular, joint and skin origin representing 30.3%, 27.7% and 18.9% respectively. Skin injuries were primarily a result of direct trauma while joint and muscular injuries were mainly a result of manoeuvres performed and repetitive actions. Key risk factors which increased the incidence of sustaining an acute injury included competitive status, hours surfed (> 6.5 hr · week) and the ability to perform aerial manoeuvres. The incidence proportion for surfers completing aerial manoeuvres was calculated to be 0.48, 95% CI (0.39-0.58) major injuries per year, this being the highest IP irrespective of competitive status. Conclusion: This is the largest surfing specific survey which included both recreational and competitive surfers conducted within Australia to date. We identified the shoulder, ankle, head and face are the key regions where acute injuries occur in surfers. This research may aid in reducing the occurrence of injury through musculoskeletal screening in these key injury prone regions and the use of sports specific strength training and conditioning.

1.3.1.2. Introduction

There are an estimated 37 million surfers worldwide (Moran & Webber, 2013) with 2.5 million recreational surfers within Australia (Stark, 2010). The recreational activity and sport of surfing has grown dramatically since the 1960's, however scientific research has been poorly mirrored in comparison to most other mainstream sports.

Currently it is difficult to draw clear conclusions from previous research specific to acute surfing injuries, due to variations in research methodologies. Research conducted in hospital or emergency clinics tends to reveal high frequencies of lacerations mainly to the head and leg regions (Allen et al., 1977; Barry et al., 1982; Roger, 2002; Taylor et al., 2004); however research conducted outside the hospital or emergency setting reveals an increase in soft tissue sprains and strains which are mainly represented in the lower body regions (Nathanson et al., 2007).

Incidence definitions along with injury severity, location and type of injury appear to vary between studies (Allen et al., 1977; Barry et al., 1982; Heggie & Caine, 2012; Meir et al., 2012; Nathanson et al., 2007; Nathanson et al., 2002; Roger, 2002; Taylor et al., 2004). Mechanism of injury has been inconsistently reported and often not linked with injury location and type. These factors highlight the need to capture new acute injury related data that encompasses injury severity, location, type and mechanisms.

World-wide surfing participation has increased from an estimated 13 million in 2002 (Nathanson et al., 2002) to 37 million in 2013 (Moran & Webber, 2013). With this significant growth in participation numbers and no clear understanding of injury epidemiology in the sport of surfing, further research is needed. Therefore the aim of this study was to investigate acute injury in recreational and competitive surfers within Australia. The secondary aim was to provide a foundation for injury prevention strategies by initially understanding injury incidence, severity, location, type and mechanism in a surfing population.

1.3.1.3. Methods

A cross-sectional descriptive survey design was implemented to gather acute injury data. Due to the coastal location of surfers and the accessibility of the internet an online survey was selected as the data collection method. An on-line survey (SurveyMonkey) using an open-source specialized survey application was the tool utilized. Research ethics approval was granted by Bond University Human Research Ethics committee (RO 1540).

Surfing injury data was attained by asking each participant to retrospectively recall any acute injury which occurred while surfing in the past 12 months. A clear description of an acute injury was given at the start of the question to exclude chronic injuries and any acute injuries that were not caused from surfing. A 12 month time frame has been used in previous surf specific research (Nathanson et al., 2002; Taylor et al., 2004). The ability of a participant to recall whether an injury occurred or not in the previous 12 months has been previously shown to be 100%, however it needs to be noted that as the detail requested increases the ability of recall decreases (Gabbe, Finch, Bennell, & Wajswelner, 2003). Prospective methods are clearly ideal as this does not rely on participant memory. No systems are in place at surf clubs that record injuries making the possibility of prospectively recording injury unattainable.

To take part in the online survey participants had to be active surfers and have at least 12 months of experience (Taylor et al., 2004). Considering an estimated 2.5 million recreational surfers in Australia (Nathanson et al., 2002), to have a 95% chance that our sample proportion would be within $\pm 3\%$ of this estimated population, we needed to recruit 1067 surfers (Taylor et al., 2004). Therefore several recruitment strategies were utilized to help ensure adequate participant recruitment.

Recruitment began with sending the study overview and the survey link to local surfing clubs ($n = 103$). Next we sought support from popular Australian surfing websites (Surfing Australia, Surfing Queensland, Swellnet, Tracks, Surfrider Foundation and Surfing Life). Finally the survey was advertised through the local television networks and radio (NBN, Nine news and ABC radio). All media promotion reinforced that surfers did not have to be injured to take part in the survey. This was to ensure a true representation of the surfing population was attempted to be attained.

After initial development of the survey it was pilot tested with a group of relevant experts in the field of sports injuries and the sport of surfing. Relevant experts

included exercise scientists and physiotherapists who were on the Surfing Australia sport science and medicine panel. This was to ensure face validity and relevant questions were included. Further pilot testing occurred with 10 surfers.

In an attempt to encourage completion, questions were a range of “yes/no”, checklist and drop down options. Text boxes were offered when categorical options could not describe the injury. The survey was active online on the 25th October 2012 and remained active until 25th March 2013.

The survey consisted of three primary sections. Section one contained questions which included demographic information and participation levels (age, height, weight, hours surfed, competitive level). Participants were asked typically, how many hours they surfed per week and how many weeks per year. Competitive level was determined by offering 15 different categories of varying levels of competition. This ranged from local club level competition to the peak international competition (World Championship Tour). Participants were able to select whether they currently or previously were involved in competition. Participants were also asked whether or not they did aerial manoeuvres on a regular basis. An aerial manoeuvre was defined as ‘an ability to propel yourself and the board in the air and land back on the water standing on the board’. This was supplied in the body of the question.

Section two included questions related to acute injury for all the major regions of the body, and also incorporated injury type, mechanism, severity and injury management. In order to determine injury type, five broad types were offered to the participant. These included skin injury, bone injury, joint or ligament injury, muscle or tendon injury or marine injury. These broad injury definitions were based on previous retrospective epidemiological designs (Taylor et al., 2004; Zwingerberger et al., 2014). If an injury fell outside these categories a text box labelled ‘other’ was supplied to describe the type of injury. To determine the mechanism of injury the participant was asked to select the movement or event that occurred just before or contributed to the acute injury; these included 15 options and a text box labelled ‘other’ when no option was appropriate for the mechanism of injury. Where the option ‘other’ had been filled out by the participant data was categorised manually. This was applied for injury type and mechanism of injury and was performed by an experienced, credentialed physiotherapist.

To determine the severity, injuries were classified as either minor or major. Major injuries required one day or more off work and/or surfing and/or the participant required treatment from a health professional. Minor injuries did not interfere with

work, surfing or involve treatment from a health professional. As it is possible surfers may still participate in the sport with a current acute injury, it was deemed appropriate to classify an injury as major if the surfer received treatment but continued to participate in surfing. Previous epidemiology studies (Hadała & Barrios, 2009; Meir et al., 2012) have not combined both variables to determine severity.

In order to determine injury incidence, clear definitions must be implemented. Incidence refers to the number of new occurrences of an injury during a specified time period (Rothman et al., 2008). Risks and rates are two methods of quantifying incidence however very often these definitions are incorrectly used or authors assume they are the same (Knowles et al., 2006). Injury risk refers to the number of athletes injured divided by the number of athletes exposed to risk, this is also known as incidence proportion (IP). This answers the question, “what is the probability an athlete will be injured over a 12 month period”. Incidence rate (IR) refers to the total number of injuries divided by the total time the athlete is exposed to risk (normally per 1000 hrs). This answers the question, “what is the incidence of injury per unit of exposure”.

The use of IP is more user friendly for practitioners and coaches and allows a simple probability calculation (e.g., one in every two athletes will sustain an acute injury over the season). The definition of IR applies a more complex calculation however is used for scientific and research comparisons (i.e., 11.3 injuries per 1000 hours). Both of these definitions will be used within this paper.

A participant could report multiple injuries at several sites of the body; however recurrent acute injuries at the same location could not be captured by the survey. Chronic injuries were analysed in the third section of this survey, however for the purpose of this study this section was not included.

Descriptive statistics and frequencies were used to summarise each variable. Significant differences ($p \leq .05$) were determined between groups using independent t-tests for continuous data. For categorical variables a Chi-square test of independence was used to determine differences between variables. All statistical analysis was completed using Statistical Package for the Social Sciences (Version 20.0).

1.3.1.4. Results

A total of 1582 participants commenced the survey however 234 participants had a significant amount of data not completed and consequently were excluded from data analysis. Therefore 1,348 participants (91.3% males, 43.1% competitive surfers) were included in the data analysis. It is not possible to provide an estimation of the percentage of respondents to non-respondents due to the extremely broad outreach to participants through the several promotional strategies used to advertise the survey (websites, television, radio and email).

The mean age was 35.8 ($SD = 13.08$; range 11-70) years, with a median of 35.0 years. Males were significantly older ($t = 4.00$, $p < .001$) with the mean age being 36.2 years compared to females (31.87 years). Key physiological and surfing demographics are summarized in Table 5. Of 1,348 surfers, a total of 512 participants reported sustaining an acute major injury. As more than one injury could be reported by a participant a total of 739 injuries were classified as major.

Table 5: Participants Physiological and Surfing Demographics

Physiological Demographics	Total ($n=1348$)	Male ($n=1231$)	Female ($n=117$)
Age (years.)	35.8 ± 13.1	36.2 ± 13.2	31.9 ± 11.1
Weight (kg)	78.6 ± 12.8	80.2 ± 11.9	61.4 ± 8.2
Height (cm)	178.2 ± 9.0	179.2 ± 8.5	167.3 ± 7.6
BMI (kg/m^2)	24.7 ± 3.8	25.0 ± 3.8	21.9 ± 2.4
Surfing Demographics			
Hrs per year ^a	305.5 ± 291.2 (IQR = 312) ^b	302.9 ± 282.6 (IQR = 301)	332.9 ± 369.2 (IQR = 423)
Competitive involvement ^c	581	526	55

^aHrs per year was calculated by adding the total hours per week and weeks per year together

^bInterquartile range was used for hours surfed per year due to large standard deviations (low values and some large outliers)

^cCompetitive involvement refers to any surfer who currently or has previously been involved in competitive surfing

1.3.1.4.1. Incidence Rate (IR) and Incidence Proportion (IP)

In order to determine IR (injuries per athlete hour of exposure) the total number of injuries was divided by the total number of hours surfed per year. The IR was calculated to be 1.79 major injuries per 1000 hours of surfing. As surfing has high levels of participation, IP (total injured athletes divided by total number of athletes) needed to also be examined as IR is lowered with large hours of participation. Therefore the total number of participants who had sustained an acute major injury ($n = 512$) was divided by the total number of participants who completed the survey ($n = 1348$) to determine the IP. An IP of 0.38, 95% CIs (0.35, 0.41) major acute injuries per surfer per year was determined. When considering competitive status there was a significantly higher ($\chi^2 = 6.39, p < .001$) IP compare to recreational surfers. Out of the 581 competitive surfers 243 surfers had sustained at least one major injury providing an IP of 0.42 95% CIs (0.35, 0.41) major injuries per surfer per year. Out of the 767 recreational surfers 269 surfers had sustained at least one major injury, thus providing a lower IP of 0.35 95% CIs (0.33, 0.37) major injuries per surfer per year.

Table 6: Incidence Proportion and Incidence Rate for Recreational, Competitive and Aerialist Surfers

	Major injuries*		Total	IP (95% CIs)	IR (95% CIs)
	No	Yes			
Recreational	498	269	767	0.35 (0.33-0.37)	2.18/1000 (1.98-2.42)
Competitive	338	243	581	0.42 (0.39-0.45)	1.51/1000 (1.35-1.67)
Aerialist	100	94	194	0.48 (0.39-0.58)	1.35/1000 (1.14-1.56)
Total	836	512	1348	0.38 (0.35-0.41)	1.79/1000 (1.67-1.92)

*A major injury included any injury that required the surfer to seek medical treatment and or was unable to work or surf for at least one day.
Data in brackets are confidence intervals.

1.3.1.4.2. Injury Location, Type and Mechanism

The shoulder, ankle and head/face regions had the highest frequencies of major acute injuries representing 16.4%, 14.6% and 13.3% respectively. Competitive surfers revealed a significantly ($p < .001$) higher number of knee injuries compared to recreational surfers ($n = 50$ vs. 29). Table 7 summarises the site and severity of acute injuries with comparisons between recreational and competitive surfers.

Table 7: Location of Acute Injuries for Recreational and Competitive Surfers

	Total			Recreational	Competitive	Recreational vs. Competitive
Site	<i>n</i> (%)	Minor <i>n</i> (%)	Major <i>n</i> (%)	Major <i>n</i> (%)	Major <i>n</i> (%)	Chi Square Value (<i>P</i> value)
Shoulder	154 (14.7)	33 (10.7)	121 (16.4)	60 (15.7)	61 (17.1)	2.898 (0.089)
Ankle	162 (15.5)	54 (17.5)	108 (14.6)	56 (14.7)	52 (14.6)	1.220 (0.269)
Head/Face	152 (14.5)	54 (17.5)	98 (13.3)	61 (16.0)	37 (10.4)	1.232 (0.267)
Knee	101 (9.6)	22 (7.1)	79 (10.7)	29 (7.6)	50 (14.0)	13.949 (0.001)*
Lower Back	94 (9.0)	24 (7.8)	70 (9.5)	32 (8.4)	38 (10.6)	3.766 (0.052)
Neck	85 (8.1)	17 (5.5)	68 (9.2)	37 (9.7)	31 (8.7)	0.181 (0.671)
Hip/Groin	82 (7.8)	20 (6.5)	62 (8.4)	29 (8.1)	33 (8.6)	0.358 (0.550)
Rib/Sternum	49 (4.7)	10 (3.2)	39 (5.3)	27 (7.1)	12 (3.4)	2.490 (0.115)
Upper Back	42 (4.0)	13 (4.2)	29 (3.9)	15 (3.9)	14 (3.9)	0.324 (0.569)
Shin/Calf	56 (5.3)	28 (9.1)	28 (3.8)	14 (3.7)	14 (3.9)	0.555 (0.456)
Wrist/Hand	43 (4.1)	24 (7.8)	19 (2.6)	11 (2.9)	8 (2.2)	0.008 (0.930)
Elbow	27 (2.6)	9 (2.9)	18 (2.4)	7 (1.8)	11 (3.1)	2.413 (0.120)
Totals	1047 (100)	308 (100)	739 (100)	382 (100)	357 (100)	

Note; the total major injuries are listed in descending order

n= number of injuries at each location

*Significant differences ($p \leq .05$)

Injuries were predominantly of muscular (31.3%), joint (28.7%), skin (17.2%) and nerve (6.9%) origin (Table 8). The remaining 4% encompassed eye, ear, concussion, sacroiliac injury and pneumothorax. Categories at each location of the body were added together to provide the overall percentages above. A complete break-down of injury types at each location can be seen in Table 8.

Of the total number of mechanisms of injuries 47.1% were a result of direct trauma with either a surfer's board or contact with the ocean floor. The remaining mechanisms occurred while the surfer was paddling (10.9%), duck diving (4.6%), wave riding (32.7%) and aerial surfing (4.6%). Acute shoulder injuries commonly resulted from paddling (25.6%); meanwhile head and face injuries were predominantly a result of direct trauma/contact injuries (83.7%). Ankle injuries resulted from direct trauma (54.6%), wave riding (30.6%) and aerial manoeuvres (13.9%). The major mechanisms of acute knee injuries occurred during wave riding (73.7%). Each of the categories for mechanism of injury can be seen in Table 9. This table also gives a complete breakdown of the different mechanisms of injury at each location.

Table 8: Injury Type and Location of Major Injuries for Recreational and Competitive Surfers

Site (n, %)	Type of Injury	Total No. of major injuries n, (%)	Recreational n, (%)	Competitive n, (%)
Head/Face 98, (13.3)	Skin Injury ¹	76 (64.4)	46 (65.7)	30 (62.5)
	Bone Injury ²	15 (12.7)	11 (15.7)	4 (8.3)
	Marine Injury ³	7 (5.9)	2 (2.9)	5 (10.4)
	Ear Injury ⁴	12 (10.2)	7 (10.0)	5 (10.4)
	Eye Injury ⁵	5 (4.2)	2 (2.9)	3 (6.25)
	Concussion ⁶	3 (2.5)	2 (2.9)	1 (2.1)
Neck 68, (9.2)	Skin Injury	1 (1.0)	1 (1.8)	-
	Bone Injury	7 (7.2)	4 (7.3)	3 (7.1)
	Joint Injury ⁷	24 (24.7)	16 (29.0)	8 (19.0)
	Muscular Injury ⁸	40 (41.2)	21 (38.2)	19 (45.2)
	Nerve Injury ⁹	24 (24.7)	12 (21.8)	12 (28.6)
	Marine Injury	1 (1.0)	1 (1.8)	-
Shoulder 121, (16.4)	Skin Injury	4 (2.5)	3 (4.1)	1 (1.2)
	Joint Injury	70 (44.6)	38 (52.1)	32 (38.1)
	Bone	7 (4.5)	3 (4.1)	4 (4.8)
	Muscular Injury	62 (39.5)	27 (37.0)	35 (41.7)
	Nerve Injury	10 (6.4)	1 (1.4)	9 (10.7)
	Marine Injury	4 (2.5)	1 (1.4)	3 (3.6)
Elbow 18, (2.4)	Skin Injury	3 (15.0)	1 (11.1)	2 (18.2)
	Joint Injury	6 (30.0)	3 (33.3)	3 (27.3)
	Bone	3 (15.0)	2 (22.2)	1 (9.1)
	Muscular Injury	7 (35.0)	3 (33.3)	4 (36.4)
	Nerve Injury	1 (5.0)	-	1 (9.1)
Wrist/Hand 19, (2.6)	Skin Injury	7 (30.4)	6 (42.9)	1 (11.1)
	Joint Injury	9 (39.1)	5 (35.7)	4 (44.4)
	Bone	3 (13.0)	1 (7.1)	2 (22.2)
	Muscular Injury	2 (8.7)	1 (7.1)	1 (11.1)
	Nerve Injury	2 (8.7)	1 (7.1)	1 (11.1)
Upper-back 29, (3.9)	Skin Injury	2 (6.1)	2 (11.1)	-
	Joint Injury	7 (21.2)	4 (22.2)	3 (20.0)
	Bone	4 (12.1)	2 (11.1)	2 (13.3)
	Muscular Injury	18 (54.5)	8 (44.4)	10 (66.7)
	Nerve Injury	2 (6.1)	2 (11.1)	-
Ribs/Sternum 39, (5.3)	Skin Injury	6 (12.2)	4 (11.1)	2 (15.4)
	Joint Injury	7 (14.3)	3 (8.3)	4 (30.8)
	Bone	23 (46.9)	19 (52.8)	4 (30.8)
	Muscular Injury	10 (20.4)	7 (19.4)	3 (23.1)
	Nerve Injury	1 (2.0)	1 (2.8)	-
	Marine Injury	1 (2.0)	1 (2.8)	-
	Pneumothorax	1 (2.0)	1 (2.8)	-

Lower-back 70, (9.5)	Skin Injury	10 (10.0)	5 (11.1)	5 (9.1)
	Bone Injury	4 (4.0)	2 (4.4)	2 (3.6)
	Joint Injury	31 (31.0)	13 (28.9)	18 (32.7)
	Muscle Injury	32 (32.0)	15 (33.3)	17 (30.9)
	Nerve Injury	18 (18.0)	9 (20.0)	9 (16.4)
	Marine Injury	5 (5.0)	1 (2.2)	4 (7.3)
Hip 62, (8.4)	Skin Injury	6 (7.4)	3 (7.0)	3 (7.9)
	Bone Injury	4 (4.9)	2 (4.7)	2 (5.3)
	Joint Injury	20 (24.7)	11 (25.6)	9 (23.7)
	Muscular Injury	45 (55.6)	26 (60.5)	19 (50.0)
	Nerve Injury	5 (6.2)	1 (2.3)	4 (10.5)
	SIJ ¹⁰	1 (1.2)	-	1 (2.6)
Knee 79, (10.7)	Skin Injury	5 (5.0)	3 (8.8)	2 (3.0)
	Joint Injury	52 (52.0)	17 (50.0)	35 (53.0)
	Bone	7 (7.0)	4 (11.8)	3 (4.5)
	Muscular Injury	36 (36.0)	10 (29.4)	26 (39.4)
Shin/Calf 28, (3.8)	Skin Injury	16 (47.1)	8 (47.1)	8 (47.1)
	Bone	4 (11.8)	2 (11.8)	2 (11.8)
	Muscular Injury	12 (35.3)	6 (35.3)	6 (35.3)
	Marine Injury	2 (5.9)	1 (5.9)	1 (5.9)
Ankle 108, (14.6)	Skin Injury	44 (31.4)	25 (34.7)	19 (27.9)
	Joint Injury	38 (27.1)	18 (25.0)	20 (29.4)
	Bone	32 (22.9)	16 (22.2)	16 (23.5)
	Muscular Injury	24 (17.1)	12 (16.7)	12 (17.6)
	Marine Injury	2 (1.4)	1 (1.4)	1 (1.5)

Skin injuries includes lacerations, abrasions, bruising and haematomas. ² Bone injuries includes fractures and other bony pathologies (avulsions, bone bruising). ³ Marine injuries include stings and bites (the type of sea creature is not defined). ⁴ Ear injury includes ear drum perforations and any other acute ear pathologies. ⁵ Eye injury includes, eye ball and eye socket pathologies. ⁶ Concussion includes loss of consciousness and other brain injuries. ⁷ Joint injury includes ligamentous sprain, cartilage damage, discal injury, dislocation, subluxation, bursitis. ⁸ Muscular injury includes, strain, tear and rupture. ⁹ Nerve injury includes neural compression, stretch or other nervous injury. ¹⁰ SIJ includes sacro-iliac joint injuries or dysfunction.

Table 9: Site and Mechanism of Major Acute Injuries

	Mechanism of Injury	Head/Face	Neck	Shoulder	Elbow	Wrist/Hand	Upper-back	Sternum/ribs	Lower-back	Hip/Groin	Knee	Shin/Calf	Ankle/Foot	Totals
Direct trauma/contact injuries	Struck by own board	51	1	4	1	4	-	14	2	3	7	9	25	121
	Struck by other surfers board	11	-	2	2	1	2	2	2	1	-	5	2	30
	Striking sea floor/ bottom	11	20	18	4	6	4	4	11	3	8	4	31	124
	Striking surface of sea	9	14	26	-	-	3	7	12	6	2	1	1	80
	Paddling	-	13	31	4	-	9	7	10	3	4	-	1	82
	Duck diving	2	5	9	3	3	3	1	1	3	4	1	-	35
Actual wave riding	Take off	2	3	6	2	3	2	1	10	7	9	1	9	55
	Bottom turn	-	1	1	-	-	2	-	1	5	7	1	1	19
	Top turn	-	-	1	-	-	1	1	7	3	9	1	3	26
	Cut back	-	-	2	-	-	-	-	5	3	7	-	1	18
	Re-entry	1	-	1	-	-	-	1	2	6	9	3	5	28
	Floater	-	-	1	-	-	-	-	2	2	3	-	4	12
	Riding the face of the wave	2	-	2	-	-	1	-	1	7	6	-	2	21
	Tube riding	7	11	17	2	2	2	-	1	7	10	-	8	67
	Aerial	2	-	-	-	-	-	1	3	2	10	2	15	35
	Totals	98	68	121	18	19	29	39	70	61	95	27	108	753

1.3.1.4.3. Risk Factors

Competitive status resulted in significantly more acute injuries than the recreational group. There was also a significant difference ($t = 11.0$, $p < .001$) between hours surfed for competitive versus recreational surfers (mean values 406.9 vs.. 228.7 hrs · year). As expected those suffering an acute injury (major only) on average spent significantly ($t = 5.5$, $p < .001$) more time surfing (360.4 vs.. 271.8 hrs · year) than those who were uninjured.

A total of 194 surfers who completed the survey were able to complete aerial manoeuvres on a regular basis (meaning the surfer can propel themselves into the air and land back onto the wave). Of the 194 surfers who could complete such manoeuvres a total of 94 surfers sustained a major acute injury within a 12 month period. The IP was calculated to be 0.48, 95% CI (0.39, 0.58) major injuries per year, this being the highest IP irrespective of competitive status. Chi-Square test revealed a significant increase ($\chi^2 = 10.5$, $p < .001$) in the group of surfers that were able to perform aerials and sustained a major injury versus the group that sustained a major injury but were unable to complete aerials (94 of 194 vs.. 418 of 1154). Of the 94 surfers who could complete aerials and sustained a major injury 76.0% were located to the lower body which was significantly higher ($\chi^2 = 30.5$, $p < .001$) than the number of upper body injuries (24.5%) associated with the group of surfers who were able to complete aerial manoeuvres.

1.3.1.5. Discussion

This study appears to be the largest Australian national survey to date conducted on acute surf specific injuries. The purpose of this study was to explore injury incidence severity, location, type and mechanism for recreational and competitive surfers and provide a foundation for injury prevention strategies. Results have revealed both similarities and differences to previous research.

The demographical data (Table 5) of this survey revealed that surfers on average have BMI's within the normal to high ranges (male's avg. $25.0 \pm 3.8 \text{ kg} \cdot \text{m}^2$, females $21.9 \pm 2.4 \text{ kg} \cdot \text{m}^2$). However, BMI does not take into consideration tissue differences (i.e., lean body mass versus adiposity). Given their high degree of participation levels exceeds the World Health Organisation guidelines (WHO, 2011) on physical activity, it is assumed the higher BMI's seen in male surfers may actually be a reflection of increased lean body mass, which we are currently investigating.

This study found an overall IR of 1.79/1000 and an overall IP of 0.38 major injuries per year. It also found that when grouped, both competitive and aerial surfers had the lowest IR (1.51 and 1.35 respectively) however, they both had the highest IP rates (0.42 and 0.48 respectively). It appears that the high rate of participation for the competitive and aerial surfers weakens the IR however both groups have the highest risk of being injured. Both measures of incidence are valuable for two types of questions; if an athlete wants to know whether or not he or she has a chance of being injured by competition or performing aerials knowing the IP is more useful than the IR. The IP measure is also more easily understood by coaches and trainers as it provides the probability of injury. It also may motivate both the coach and athlete to engage in exercises to help reduce the potential for injury (proprioception, strength and flexibility). If a researcher wants to know the quantity of injuries per unit and compare between sports, knowing the IR is more appropriate.

The current IR of 1.74 injuries per 1000 hours was similar to previous surf specific research (Meir et al., 2012; Taylor et al., 2004) where injury rates were based on hours of exposure. The present study found an overall IP of 0.37 major acute injuries per surfer per year. Therefore one in every three surfers will sustain an acute injury which will either require medical treatment or cause the surfer to take time off work and or surfing.

A study conducted by Meir et al. (2012) revealed a very similar IP of 0.38 major injuries per surfer per year. This study was also a retrospective design which used an

online survey to attain information. However several other surf specific and surf life-saving studies (Lowdon et al., 1987; Mitchell, Brighton, & Sherker, 2012; Roger, 2002) have either not included IP or IR due to lack of participation data or have calculated IR based on days of exposure (Allen et al., 1977; Lowdon et al., 1987), therefore it is difficult to draw comparisons.

Considering the low IR (1.79 injuries per 1000 hours) surfing appears relatively safe, especially when compared to mainstream sports such as Australian football where the injury rate is 25.7 injuries per 1000 playing hours (Orchard & Seward, 2002). It could be hypothesised that the lack of sudden acute injuries and high participation levels may allow the surfer to develop chronic or over-use injuries which may not present as a sudden injury or be even painful until the condition is well established (Leadbetter, 1992). Chronic injuries often require more extensive treatment impacting the person physically, socially and economically (Pinzon & Larrabee, 2006). This validates the need to screen surfers to identify injury prone areas and potentially prevent both acute and chronic injuries.

The shoulder had the highest number of acute major injuries followed by the ankle and the head and face region. Shoulder injuries have not previously been shown to have the highest frequency of acute injuries. However this is surprising as ~45% of a surfing session involves paddling (Meir, Lowdon, & Davie, 1991; Secomb, Sheppard, & Dascombe, 2015). Paddling involves predominantly large global muscular strength, with the movements of initially abduction followed by adduction and internal rotation. It could be hypothesised that muscle asymmetry occurs between the strength of the internal rotators and the posterior external rotators of the shoulder. Previous research has shown associations between shoulder pathology and muscle tightness and weakness in the posterior rotator cuff in upper body sports such as swimming and tennis (Pinzon & Larrabee, 2006).

The high number of ankle injuries may reflect the change in surfing styles over the past decade. This may be seen with surfers now attempting aerial manoeuvres; if the landing is not correct it can result in excessive load at the ankle. Surfers attempt to descend from the air back onto the wave where the declining angle of the wave is used to reduce the impact on the lower limb. If the surfer lands in front of the wave on the flat section the ankle may be subject to injury. It could be hypothesised that adequate ankle range of motion and proprioception is a prerequisite before attempting such difficult manoeuvres; screening surfers to detect whether the above is present could possibly reduce such injuries. Previous research has also shown a high

incidence of head and lower limb injuries (Meir et al., 2012; Nathanson et al., 2002; Taylor et al., 2004), thus supporting our findings.

The most common types of injuries were related to a muscular, joint and skin origin representing 31.3%, 28.7% and 17.2% respectively. The results of this study may be a reflection in the change of current surfing style and board design. Advances in board design have allowed for lighter and smaller boards. This allows for the board and the surfer to more easily manoeuvre on the wave and perform radical torsional movements, it also allows for aerials as described previously. These movements may place increased stresses on ligamentous and contractile tissues and possibly explain the rise in muscular and joint injuries.

High numbers of muscular and joint injury types differed to the findings of previous research (Lowdon et al., 1987; Nathanson et al., 2002; Taylor et al., 2004) especially if the data was collected within emergency departments (Roger, 2002; Taylor et al., 2004) where the main type of injury was of skin origin usually a result of direct trauma from a surfer's board. This may again be a reflection in the change of surfing styles over the past decade.

This study has revealed that approximately half of the mechanisms of injuries occur while the surfer is paddling, duck diving or actual wave riding (non-contact); the remaining mechanisms were due to contact injuries (direct trauma). Previous research (Meir et al., 2012) has either not included specific mechanisms of injury or partially reported and or hypothesised the mechanism of injury (Bentley, Macky, & Edwards, 2006; Nathanson et al., 2002). Research conducted by Roger (Roger, 2002) revealed that 100% of all injuries were a result of contact injuries. Several other studies have previously reported the mechanisms of injuries mainly due to contact injuries (direct trauma) (Barry et al., 1982; Lowdon et al., 1983; Lowdon et al., 1987). These findings when compared to previous research reveal an increase in non-contact mechanisms. Non-contact injuries involve movements (take off, turning, floater, aerials and tube riding) where the surfer is injured without direct trauma from the surf board or sea floor. It could be hypothesised that conditioning of muscles and joints, which are prone to injury, may prepare these regions during these particular movements.

The rise in non-contact mechanisms could also be attributed to the survey having a wide range of choices of injury mechanism (see Table 5). A study conducted by Roger (2002) used only contact mechanisms including; being struck by the surfers

own board, being struck by someone else's board and other (e.g. rocks). The limited mechanism choices can bias the results toward contact injuries (direct trauma).

This research has highlighted a number of risk factors for acute injury including increased participation levels, competitive history and the ability to perform aerial manoeuvres. Identifying these factors may assist clinicians identifying high risk surfers and ensuring injury prehabilitation exercises are implemented.

This research has provided an extensive foundation for further injury prevention research. As with any sport understanding injury incidence, severity, location, type and mechanism are the initial steps to be taken prior to any form of injury prevention program being implemented (Vanmechelen, Hlobil, & Kemper, 1992). The current findings are also extremely useful for the coach, strength and conditioning practitioner and physical therapist dealing with a surfer. Coaches may carefully select waves which aeriels will be attempted on or implement land based techniques to ensure correct technique and safe landings on a stable surface prior to entering unstable and unpredictable wave environments. Strength and conditioning practitioners may look to implement strengthening of opposing muscles which aren't utilised during paddling, thus trying to limit muscle imbalance and shoulder impingement. Therapists may wish to screen key joints (ankle and shoulders) for underlying muscle tightness, weakness and passive joint range of motion.

There are several limitations of this survey and mainly due to the data gathered being retrospective. As this relies upon the memory of the participant there is clearly room for error, especially as the rate of recall reduces as the detail of the injury increases (Jenkins et al., 2002). There was no formal evaluation of the reported injuries therefore the reliability of the injury type is questionable and results should be viewed with caution. Ideally future surfing injury epidemiology studies should consider prospective data methods collected from health professionals. In order to do this joint collaboration between surfing organisations is needed. Methods of recording injuries need to be consistent and easily repeatable. However considering the inconsistent surf club competitions/ training sessions and the high participation hours outside of organised club meetings, injuries sustained could easily be missed and not recorded.

Another limitation of the study is that surfers who were already injured were possibly more likely to participate in the survey. To limit bias towards injured surfers the advertisements clarified that all surfers were able to participate injured or not. This survey was also not tested for reliability; therefore, the repeatability of this survey cannot be determined. It also needs to be noted that using an online data collection

tool limits use to surfers who can access the internet and use a computer. This is a limitation however it provided the opportunity of widespread participation throughout Australia. Finally, as multiple injuries at the same location could not be reported; the injury rate is presumably lower than would be expected.

1.3.1.6. Conclusion

This appears to be the largest surfing specific survey which has included both recreational and competitive surfers conducted within Australia to date. Our findings will provide clinicians with fundamental information regarding injury prone regions specific to surfing. We were able to identify that the shoulder, ankle, head and face are the key regions where acute injuries occur in surfers. The results of our research have identified an increase in muscular and joint injuries along with providing insight into the mechanisms of injury related to specific body regions. Further, this research may aid in reducing the occurrence of injury through screening awareness and the use of sports specific strength training and conditioning. Future studies which evaluate screening of the aforementioned injury regions in surfers may provide further information for more robust prevention measures to be developed.

1.3.2. RETROSPECTIVE ANALYSIS OF CHRONIC INJURIES IN RECREATIONAL AND COMPETITIVE SURFERS: INCIDENCE, LOCATION, TYPE AND MECHANISM

The results of Study 1 for chronic injuries are presented in the following paper. This is the Accepted Author Manuscript reprinted, by permission, from the International Journal of Aquatic Research and Education, 2014, 8 (3): 277-287, <http://dx.doi.org/10.1123/ijare.2013-0032>. © Human Kinetics.

Furness, J., Hing, W. A., Abbott, A., Walsh, J., Sheppard, J. M., & Climstein, M. (2014). Retrospective analysis of chronic injuries in recreational and competitive surfers: injury location, type, and mechanism. *International Journal of Aquatic Research and Education*, 8(3), 277-287.

1.3.2.1. Abstract

Only two published studies have specifically reported on chronic musculoskeletal injuries associated with surfing. These studies reported over half of the injuries to be of non-musculoskeletal origin and did not consider mechanisms of injury. Therefore the purpose of this study was to identify the location, type and mechanisms of chronic injury in Australian recreational and competitive surfers. The study design was a cross-sectional retrospective observational study. Participants completed an online survey consisting of two sections: demographics and chronic injury. A total of 1,348 participants (91.3% males, 43.1% competitive surfers) were included in the data analysis, 1,068 chronic injuries were reported with 883 classified as major. The lower back, shoulder and knee regions had the largest distributions of chronic injury representing 23.2%, 22.4% and 12.1% respectively. Competitive surfers revealed a significantly ($p < .05$) higher number of lower back, ankle/foot and head/face injuries compared to recreational surfers. Injuries were predominantly of musculoskeletal origin with only 7.8% of all chronic injuries being of non-musculoskeletal origin. Prolonged paddling had the highest frequency (21.1%) for any mechanism of injury followed by turning manoeuvres at 14.8%. The results of this study contribute to the limited research investigating chronic surfing injuries. The high number of chronic musculoskeletal injuries and mechanisms of injury were previously not reported. Identifying the location, type and mechanisms of chronic injury aids in the development of prevention strategies and provides clinicians with direction for objective screening for the surfing population.

1.3.2.2 Introduction

Early research conducted by Nathanson et al. (2002) estimated there to be 18 million surfers worldwide; however current research now estimates this number to be approximately 37 million (Moran & Webber, 2013). The recreational activity and sport of surfing has grown dramatically since the 1960's, though scientific research has been poorly mirrored in comparison to most other mainstream sports.

When reviewing an injury it is important to consider the stage of injury (acute or chronic). Acute injury has been defined as a sudden onset of sharp pain or sudden impact that the person can relate to a specific situation, normally resulting in tissue damage in a localised region (Askling et al., 2002). To date, there are less than 20 studies exploring acute injuries in both recreational and competitive surfers and although these studies exist it is difficult to draw clear conclusions due to variations in research methodologies. Earlier findings have revealed high frequencies of lacerations mainly to the head and leg regions (Allen et al., 1977; Barry et al., 1982) with more recent research reporting an increase in soft tissue sprains and strains to the lower body regions (Meir et al., 2012; Nathanson et al., 2007). Acute injury research has also revealed very low injury rates ranging from 2.2 to 3.5 per 1,000 hr of recreational surfing (Lowdon et al., 1983; Nathanson et al., 2002; Taylor et al., 2004) and slightly higher at 6.6 per 1,000 hr for competitive surfing (Nathanson et al., 2007).

If an acute injury is poorly rehabilitated or residual symptoms persist it is believed the injury can predispose the person to re-injury at the same site (Heggie & Caine, 2012). Residual symptoms such as restricted joint range of motion may lead to muscle atrophy and increased compensatory stress on other joints resulting in further musculoskeletal damage (Heggie & Caine, 2012). Both re-injury and residual symptoms associated with an acute injury can lead to chronic injury (also known as repetitive strain or overuse injuries).

Chronic injury is often defined as persistent or episodic pain lasting more than three months (Jordan et al., 2010). It can be a gradual onset of pain with no definitive mechanism of injury, or the result of an acute injury poorly rehabilitated with residual symptoms (Pinzon & Larrabee, 2006). The pathogenesis of chronic injury commences with muscle fatigue due to repetitive overload (tissues fail to adapt to increased loads), and may involve bone, ligament and most commonly musculotendinous structures. The muscle unit then tightens and may undergo

physiological changes which often results in muscle spasms and tissues shortening. This incidentally leads to muscle weakness, leaving the muscle prone to re-injury and establishing a cycle of tissue damage (Kannus, 1997). Chronic injuries outnumber acute instantaneous injuries in almost every athletic activity (Wilder & Sethi, 2004). Chronic injuries however do not result in sudden loss of function; they are generally under-reported and attract less medical attention than acute disabling injuries. When individuals present for treatment for chronic injuries, the problem is usually well established and can be difficult to manage (Pinzon & Larrabee, 2006).

A recent review of the literature identified only two studies that have analysed chronic musculoskeletal injuries in a surfing population (Nathanson et al., 2002; Taylor et al., 2004). Nathanson et al., (2002) identified that approximately half of all chronic injuries were classified as an overuse syndrome involving the musculoskeletal system. Taylor et al., (2004) revealed similar results with approximately half of all chronic injuries reported having some form of musculoskeletal origin. Survey based data collection methods were used in both studies and the exact type of chronic injury was identified as either an overuse syndrome or a chronic injury of musculoskeletal origin. A limitation of both of these studies, however, was that chronic injuries were broadly categorised, and the type or origin (nerve, joint or muscular) of injury was not identified. The mechanism of injury was briefly addressed however no clear data was available in either study.

Given the paucity of research investigating chronic musculoskeletal injuries in a surfing population and the significant increase in participation, the primary aim of this research project was to identify the location, type and mechanisms of chronic injuries in a surfing population. We hypothesised that the lack of sudden acute injuries (Meir et al., 2012) in current research and high participation levels would result in higher frequencies of chronic musculoskeletal injuries compared to the current two studies. A secondary aim was to determine risk factors for chronic injuries in a surfing population.

1.3.2.3 Methods

This was a cross-sectional descriptive survey design. Research ethics approval was attained from the Bond University Human Research Ethics committee (RO 1540). An internet survey was developed and utilized to allow for national data collection as the diverse coastal locations of surfers and the accessibility of the internet would allow for increased participation.

1.3.2.3.1. Data Collection

Survey Monkey was the tool used to construct and deliver the online survey. To participate respondents had to be active surfers and have at least 12 months of experience; the survey was active online for five months.

The survey consisted of two primary sections. Section one had questions that included demographic information and participation levels. Section two included questions related to chronic injury for all the major regions of the body, and also incorporated injury type, mechanism, severity and injury management. Chronic injury was defined as a condition that occurred over a period of time with gradual onset of symptoms that did not have to be attributed to one specific event that resulted in pain or discomfort (Pluim et al., 2009). For the injury to be classified as chronic it needed to have been present for three months or more (Jordan et al., 2010). This included injuries where the severity may vary dependent upon the amount of surfing performed. For chronic injuries to be included they had to be caused or aggravated by surfing. A participant could report a chronic injury if they were previously or currently suffering from symptoms.

To determine the severity, chronic injuries were classified as either minor or major. Previous research by Nathanson et al., (2002) used the terms minor or significant, however, to reduce confusion the classification 'significant' was replaced with 'major'. Major injuries required one day or more of time off work and/or surfing and/or the participant required treatment from a health professional. Minor injuries did not interfere with work, surfing or involve treatment from a health professional.

1.3.2.3.2. Data Analysis

Descriptive statistics and frequencies were used to summarise each variable. Significant differences ($p < .05$) between groups within the sample were analysed using Independent t-tests. For categorical variables a Chi-square test of independence was used to determine differences between variables. All statistical analysis was completed using Statistical Package for the Social Sciences (Version 20.0).

Data was categorised manually where the option 'other' had been filled out by the participant. This was applied for injury type and mechanism of injury and was performed by an experienced physiotherapist. Where there was no clarity to the type or mechanism of injury the injury type was classified as 'unspecified' and the mechanism was classified as 'unknown.'

1.3.2.4 Results

A total of 1,582 respondents commenced the survey, however only 1,348 were included in the data analysis as 234 respondents were deleted due to incomplete data. A total of 1,231 (91.3%) males and 117 (8.7%) females were included in the data analysis. The overall mean age was 35.8 ($SD = 13.1$; range 11-70) years, with a median of 35.0 years. Males were significantly older ($t = 4.0$, $p < .001$) compared to females (M age 36.2 vs. 31.9 years). The mean hours surfed per week was 6.7 ($SD = 5.6$) for males and 7.3 ($SD = 6.8$) for females. Of the total 1348 surfers, 581 had previously or were currently involved in competitive surfing locally, nationally or internationally.

Of 1,348 (1231 males, M age = 36.2, $SD = 13.2$; 117 female, M age = 31.9, $SD = 11.1$) surfers, 477 (35.4%) reported suffering from a chronic injury caused or aggravated by surfing. As more than one injury could be listed a total of 1,068 chronic injuries were reported (refer to Table 10 and 11).

1.3.2.4.1. Chronic Surfing Injuries by Location

Table 11 reveals the location and severity of both minor and major chronic injuries. It also reveals the distribution of chronic injuries for both competitive and recreational surfers. The lower back, shoulder and knee had the highest distributions of injuries representing 23.2%, 22.4% and 12.1%, respectively. Chi-square analyses were conducted to ascertain differences between minor and major injuries. The shoulder revealed a significance difference ($\chi^2 = 4.03$, $p = .04$) between the number of minor injuries ($n = 23$) compared with the number of major injuries ($n = 198$).

Chi-square analyses also revealed significant differences between recreational and competitive surfers where competitive surfers had significantly higher numbers of lower back ($\chi^2 = 10.98$, $p < .001$), head/ face ($\chi^2 = 5.95$, $p = .01$) and ankle/ foot injuries ($\chi^2 = 6.13$, $p = .01$). There was also a significant difference ($t = 11.0$, $p < .001$) between hours surfed for competitive versus recreational surfers ($M = 406.9$, $SD = 343.7$ vs. $M = 228.7$, $SD = 214.3$ hrs per year).

Table 10: Physiological and Surfing Demographics of Study Participants

Physiological Demographics		Male			Female		
	Total (%)	M	SD	n (%)	M	SD	n (%)
Gender	1348 (100)	-	-	1,231 (91.3)	-	-	117 (8.7)
Age (yrs)	-	36.2	13.2	-	31.9	11.1	-
Weight (kg)	-	80.2	11.9	-	61.4	8.2	-
Height (cm)	-	179.2	8.5	-	167.3	7.6	-
BMI (kg/m ²)	-	25.0	3.8	-	21.9	2.4	-
Surfing Demographics							
Hours surfed per week	-	6.7	5.6	-	7.3	6.8	-
Weeks surfed each year	-	40.7	13.5	-	38.5	15.8	-
Natural (left foot forward)	977 (72.5)	-	-	896 (91.7)	-	-	81 (8.3)
Goofy (right foot forward)	371 (27.5)	-	-	335 (90.3)	-	-	36 (9.7)
Short Board	1105 (82.0)	-	-	1032 (93.4)	-	-	73 (6.6)
Mini Mal	96 (7.1)	-	-	75 (78.1)	-	-	21 (21.9)
Long Board	147 (10.9)	-	-	124 (84.4)	-	-	23 (15.6)
1-5 years surfing	214 (15.9)	-	-	173 (80.8)	-	-	41 (19.2)
5-10 years surfing	218 (16.2)	-	-	189 (86.7)	-	-	29 (13.3)
10-15 years surfing	217 (16.1)	-	-	194 (89.4)	-	-	23 (10.6)
15-20 years	154 (11.4)	-	-	142 (92.2)	-	-	12 (7.8)
20-25 years	119 (8.8)	-	-	113 (95.0)	-	-	6 (5.0)
25-30 years	123 (9.1)	-	-	119 (96.7)	-	-	4 (3.3)
30-35 years	99 (7.3)	-	-	98 (99.0)	-	-	1 (1.0)
35 years plus	204 (15.1)	-	-	203 (99.5)	-	-	1 (0.5)
Competitive involvement*	581 (43.1)	-	-	526 (90.5)	-	-	55 (9.5)

*Refers to any surfer who has previously or currently involved in competition surfing locally, nationally or internationally.

1.3.2.4.2. Chronic Surfing Injuries by Type

Table 12 reveals the location of injury with a categorical breakdown of the type of injury. In order to simplify the extensive amount of data, types of injuries were classified into broader terms. Injuries of joint origin represented 43.5% ($n = 528$), muscular origin 23.6% ($n = 286$), nerve origin 4.6% ($n = 56$), skin 0.5% ($n = 6$), bone origin 3.9% ($n = 47$) unspecified 16.2% ($n = 197$) and non-musculoskeletal origin 7.7% ($n = 94$).

Table 11: Location of both Minor and Major Chronic Injuries for Recreational and Competitive Surfers

				Recreational	Competitive
Site	Total (Major & Minor) n , (%)	Minor n , (%)	Major n , (%)	Major n , (%)	Major n , (%)
Lower Back	224 (21.0)	19 (10.3)	205 (23.2)	95 (21.3)	110 (25.8)
Shoulder	221 (20.1)	23 (12.4)	198 (22.4)	110 (24.7)	88 (20.1)
Knee	129 (15.8)	22 (11.9)	107 (12.1)	53 (11.9)	54 (12.6)
Neck	102 (9.6)	13 (7.0)	89 (10.9)	49 (11.0)	40 (9.2)
Thoracic region	78 (7.3)	22 (11.9)	56 (6.3)	29 (6.5)	27 (6.2)
Head/Face	77 (7.2)	19 (10.3)	58 (6.6)	24 (5.4)	34 (7.8)
Hip/Groin	73 (6.8)	17 (9.2)	56 (6.3)	31 (7.0)	25 (5.7)
Elbow	56 (5.2)	18 (9.7)	38 (4.3)	24 (5.4)	14 (3.2)
Ankle/Foot	55 (5.1)	9 (4.9)	46 (5.2)	18 (4.0)	28 (6.4)
Wrist/Hand	42 (3.9)	20 (10.8)	22 (2.5)	10 (2.2)	12 (2.7)
Shin/Calf	11 (1.0)	3 (1.6)	8 (0.9)	3 (0.7)	5 (1.1)
Total	1068 (100)	185 (100)	883 (100)	446 (100)	437 (100)

1.3.2.4.3. Chronic Surfing Injuries by Mechanism

Table 13 represents the mechanisms associated with the location of chronic injury. Prolonged paddling had the highest total frequency for any mechanism of injury at 21.1%, followed by turning manoeuvres at 14.8%. Trauma from the force of the wave only represented 1.5%. Environmental exposure which included prolonged exposure of the water, sun and wind represented 5.6% as a mechanism of chronic injury.

1.3.2.4.4. Key Risk Factors

The data analysis demonstrated older surfers ($M = 39.3$, $SD = 12.0$ vs.. $M = 33.9$, $SD = 13.3$ years) were more likely to sustain a chronic injury ($t = 7.6$, $p < 0.001$) whilst surfing. There was no significant difference ($t = 0.38$, $p = .11$) between prevalence of chronic injury and hours spent surfing ($M = 309.6$, $SD = 272.0$ vs.. $M = 303.2$, $SD = 301.3$ hrs/year).

With regards to mechanisms of injury, paradoxically there was a significantly ($\chi^2 = 4.9$, $p < .05$) higher likelihood of sustaining a chronic injury in surfers who did not complete aerial manoeuvres (28.9% vs.. 36.5%). There was a significantly ($\chi^2 = 4.5$, $p = .03$) greater number of chronic injuries (minor or major) in recreational surfers compared with competitive surfers ($n = 253$ vs. 224).

Chi-square analysis was performed for all lower limb injuries to determine whether there was a significant difference between chronic injuries to the front versus back leg. Surprisingly, no significant differences were found in the prevalence of chronic injuries between legs.

Table 12: Site and Types of Major Chronic Injuries

Injury Origin, <i>n</i> (%)								
Injury Location	Non-Musculoskeletal ¹	Skin Origin ²	Joint Origin ³	Muscular Origin ⁴	Nerve Origin ⁵	Bone Origin ⁶	Unspecified origin ⁷	Total for locations
Head/face	94 (91.2)	4 (3.9)	-	-	-	1 (1.0)	4 (3.9)	103
Neck	-	-	55 (45.5)	31 (25.6)	4 (3.3)	-	31 (25.6)	121
Shoulder	-	-	96 (37.7)	120 (47.2)	2 (0.8)	-	36 (14.2)	254
Elbow	-	-	8 (20.5)	21 (8.3)	2 (5.1)	2 (5.1)	6 (15.4)	39
Wrist/hand	-	-	8 (36.4)	3 (13.6)	-	2 (9.1)	9 (40.9)	22
Thoracic	-	-	13 (23.6)	-	-	8 (14.5)	34 (61.8)	55
Lower back	-	-	148 (47.1)	70 (22.3)	48 (15.3)	12 (3.8)	36 (11.5)	314
Hip/groin	-	1 (1.4)	28 (40)	16 (22.9)	-	4 (5.7)	21 (30.0)	70
Knee	-	-	137 (85.6)	11 (6.9)	-	1 (0.6)	11 (6.9)	160
Shin/calf	-	1(10.0)	-	5 (50.0)	-	3 (30.0)	1 (10.0)	10
Ankle	-	-	35 (53.0)	9 (13.6)	-	14 (21.2)	8 (12.1)	66
Total types, <i>n</i> (%)	94 (7.7)	6 (0.5)	528 (43.5)	286 (23.6)	56 (4.6)	47 (3.9)	197 (16.2)	1,214

¹Non-musculoskeletal origin refers to ear injuries including auditory exostosis, otitis externa and eye injuries including pterygium and abscess. ²Skin origin refers to lacerations which required greater than 3 months healing. ³Joint origin includes osteoarthritis, discal injuries, dislocation, subluxation, cartilage injury, ligamentous injury and bursitis. ⁴Muscular origin refers to muscle over-use injury, tendon injury and general muscle pain. ⁵Nerve origin includes radiculopathy, sciatica and nerve injury. ⁶Bone origin includes bone injuries, fractures, spondylolithesis, and medial tibial stress syndrome. ⁷Unspecified origin was designated to chronic injuries where the participant was unable to identify the type of injury.

Table 13: Site and Mechanisms of Major Chronic Injuries

Mechanism of Injury	Head/ Face	Neck	Shoulder	Elbow	Wrist/ Hand	Upper- back	Lower- back	Hip/ Groin	Knee	Shin/ Calf	Ankle/F oot	Totals: n, (%)
Prolonged environmental exposure ¹	68	-	-	-	-	-	-	-	-	-	-	68 (5.6)
Keeping head up while paddling	-	70	-	-	-	-	-	-	-	-	-	70 (5.7)
Prolonged Lying on the surf board	-	8	-	-	-	23	37	-	-	-	-	68 (5.6)
Prolonged sitting on board	-	-	-	-	-	-	14	15	-	-	-	29 (2.4)
Trauma from the wave	-	8	-	-	-	-	6	3	1	-	-	18 (1.5)
Prolonged paddling	-	-	160	16	4	38	42	-	-	-	-	260 (21.1)
High intensity paddling	-	-	85	7	2	16	-	-	-	-	-	110 (8.9)
Duck diving	-	-	36	4	5	-	-	6	5	1	2	59 (4.8)
Pushing down to stand up	-	-	49	8	16	-	-	-	-	-	-	73 (5.9)
Stand up phase	-	-	-	-	-	-	2	24	36	2	12	76 (6.2)
Performing turning manoeuvres	-	16	-	-	-	8	53	25	61	3	16	182 (14.8)
Tube riding	-	-	-	-	-	-	-	7	16	1	-	24 (1.9)
Landing Aerials	-	-	-	-	-	-	3	3	16	-	9	31 (2.5)
Certain stances ²	-	-	-	-	-	-	-	-	-	-	21	21 (1.7)
Unknown ³	-	11	18	3	4	9	48	12	21	3	13	142 (11.5)

¹Includes prolonged sun, wind and water exposure

²For example, rolling a foot inwards to get more contact with the grip pad during barrel riding

³Includes any cause where the participant cannot identify one specific cause or provide alternative information

1.3.2.5 Discussion

The primary aim of this retrospective analysis was to identify the location, type and mechanism of chronic injuries incurred whilst surfing. The high frequency of chronic injuries at the lower back (23.2%), shoulder (22.4%) and knee (12.1%) highlights the stresses placed upon these locations and provide further direction for chronic injury management and prevention.

The lower back had the highest frequency of injuries compared to any other region (23.2%). This study found that 25.9% of mechanisms of chronic lower back injuries were attributed to turning manoeuvres. When the surfer is standing they are performing explosive turning, cutting and twisting movements often combining the trunk movements of flexion and rotation. These explosive and combined movements may predispose the lower back to chronic injury.

Other explanations for the high frequency of chronic lower back injuries may include the large amount of time spent in the prone position. This study found that 38.5% of the mechanisms of chronic lower back injury were attributed to both prolonged paddling and lying on the surf board, both of which involve lying prone. The lumbar spine is predominantly responsible for flexion and extension movements. During extension the facet joints (apophyseal or zygoapophyseal) of the lumbar spine are in a closed pack position (Magee, 2008). When paddling in the prone position, hyperextension is needed for three reasons. Firstly it will lift the front of the board (nose) out of the water to enable paddling, secondly it will allow for an increased arm clearance when paddling and thirdly it will allow the surfer's head to be faced in the direction he or she is paddling. If a surfer lacks adequate extension in the thoracic and cervical spine the lumbar spine may be subject to increased demands of extension and subsequently be injured.

The shoulder had the second highest frequency for chronic injuries; as a large portion of time is spent paddling it is not surprising that this study revealed prolonged paddling (45.9%) as the leading cause of shoulder injuries. The shoulder muscles are used repetitively during paddling and can be subject to fatigue thus undergoing physiological changes resulting in shortening of the muscle units (Kannus, 1997). This process may result in muscular imbalance at the shoulder region and may provide an explanation as to why the shoulder area had the second highest frequency for chronic injury. The shoulder region also revealed a significantly higher number of major injuries compared with minor injuries. This highlights the severity of shoulder injuries

as most require time off work, surfing or result in the surfer having to seek treatment from a health professional.

The knee region had the third highest frequency for chronic injuries, with the majority of injuries to the knee being of joint origin (85.6%) and 39.1% of the mechanisms associated with knee injuries were attributed to turning manoeuvres. Turning manoeuvres require a torsional movement through the entire body. The feet are fixed on a surface which is made stable by a surfer and the knee may be subject to rotational forces predisposing this region to injury.

Surfing now also incorporates aerial manoeuvres; this requires the surfer to use the wave as a ramp and launch both body and board into the air, land back on the face of the wave and redescend (Everline, 2007). The rear knee is required to maintain an intense valgus position (stress on the inside of the knee) to keep the board under the foot. This study did not show a high frequency for aerial manoeuvres as a mechanism for chronic knee injuries as this would more often be associated with acute injury. The results of this study further validate this as there was a significantly ($\chi^2=4.9$, $p<0.05$) greater association between chronic injury and surfers who did not complete aerial manoeuvres (28.9% versus 36.5%). This would be expected given those carrying chronic injury would perhaps be disinclined to complete such challenging manoeuvres.

The results from this study reveal lower frequencies of non-musculoskeletal injuries (7.7%). These injuries were classified as auditory exostosis which involves bony outgrowths which protrude into the ear canal; otitis externa, which involves trauma to the epithelial lining of the ear canal and pterygiums, which involve a clear growth of skin over the cornea. The current findings from this study highlight the musculoskeletal emphasis of chronic injuries within the surfing population. A possible explanation for the significant growth of chronic musculoskeletal injuries may be due to the change in board design and the changes in surfing style. Lighter boards have allowed for aggressive and radical manoeuvres to be performed thus placing increased stresses on the musculoskeletal system.

Only two other studies have analysed chronic musculoskeletal and non-musculoskeletal injuries in surfers (Nathanson et al., 2002; Taylor et al., 2004). Nathanson et al., (2002) revealed that the highest region of musculoskeletal over-use syndromes were located at the shoulder, followed by the back and knee at 18%, 16% and 9% respectively. Taylor et al., (2004) reported that 19.9% of chronic injuries

were represented in the spine region followed by the shoulder (10.3%) and the knee (8.2%).

Both studies revealed approximately half of the injuries were of non-musculoskeletal origin. Taylor et al. (2004) revealed that 45.8% of chronic injuries were due to environmental exposure. Nathanson et al. (2002) revealed that 21% of chronic injuries were either otitis externa or auditory exostosis and a further 12% were pterygium, cellulitis and sinusitis.

To our knowledge no information for chronic injury risk factors exists in the sport of surfing. The results of this study revealed that older surfers (>39 years) were more at risk of chronic injuries. Surprisingly there was no significant difference between the number of chronic injuries and hours spent surfing. Surfers who had a competitive history had a significantly higher number of lower back, head/ face and ankle injuries. This may be due to the aggressive torsional movements when performing turning manoeuvres especially as these surfers are more likely able to complete such difficult manoeuvres. The increase in head/ face injuries may be due to the significant increase in hours surfed by competitive surfers and therefore greater environmental exposure causing ear and eye conditions as previously discussed. This study also found a significantly greater number of chronic injuries (minor and major) for recreational surfers compared to competitive surfers. This is surprising given the manoeuvres these surfers are performing; however it may further reinforce the need to be well conditioned for the sport of surfing to negate chronic injuries. Competitive surfers are more likely to be involved in training outside of surfing and aerobically and anaerobically more accustomed to the sport of surfing.

Previous research has shown that increased age and hours surfing, competitive status and surfing larger waves (overhead or higher) increase the chance of acute injury incidence (Nathanson et al., 2007; Taylor et al., 2004). Comparisons are difficult to make as these risk factors are for acute injuries only.

A limitation of this survey is that the data gathered was retrospectively reported. Memory decay of the participant may result in poor or incorrect reporting of a previous injury (Jenkins et al., 2002). Future surfing injury surveillance studies should consider prospective data collection methods where injuries are recorded at the time of the event. Another limitation of the study is that surfers who were already injured were possibly more likely to participate in the survey. To limit bias towards injured surfers the advertisements clarified that all surfers were able to participate whether injured or not.

1.3.2.6 Conclusion

This appears to be the largest national surfing specific survey to date. Our findings will provide clinicians with fundamental information regarding injury prone regions specific to surfing. We were able to identify that the lower back, shoulder and knee are the key regions where chronic injuries occur in surfers. The results of our research have identified an increase in musculoskeletal injuries along with providing insight into the mechanisms of injury related to specific body regions. Further, this research may aid in reducing the occurrence of injury through screening awareness and the use of sports specific strength training and conditioning. Future studies which evaluate screening of the aforementioned injury regions in surfers may provide further information for more robust prevention measures to be developed.

CHAPTER 2: SURF SPECIFIC SCREENING

2.0.1 Preface

This chapter is centred on developing a surf specific screen and is divided into six sections. Section 2.1 outlines the key components of sport specific screening. Section 2.2 then presents a narrative literature review around screening techniques in surf specific studies. Section 2.3 presents the development of the musculoskeletal component of the surf specific screen. Section 2.4 and 2.5 presents two literature reviews around thoracic and shoulder assessment. Finally, section 2.6 presents Study 2, which is a reliability study. The results of this study are presented in two papers. Figure 4 illustrates the outline of the chapter.

This chapter relates to the second aim of this thesis; “To design a surf specific screen incorporating reliable and specific methods for a surfing population”.

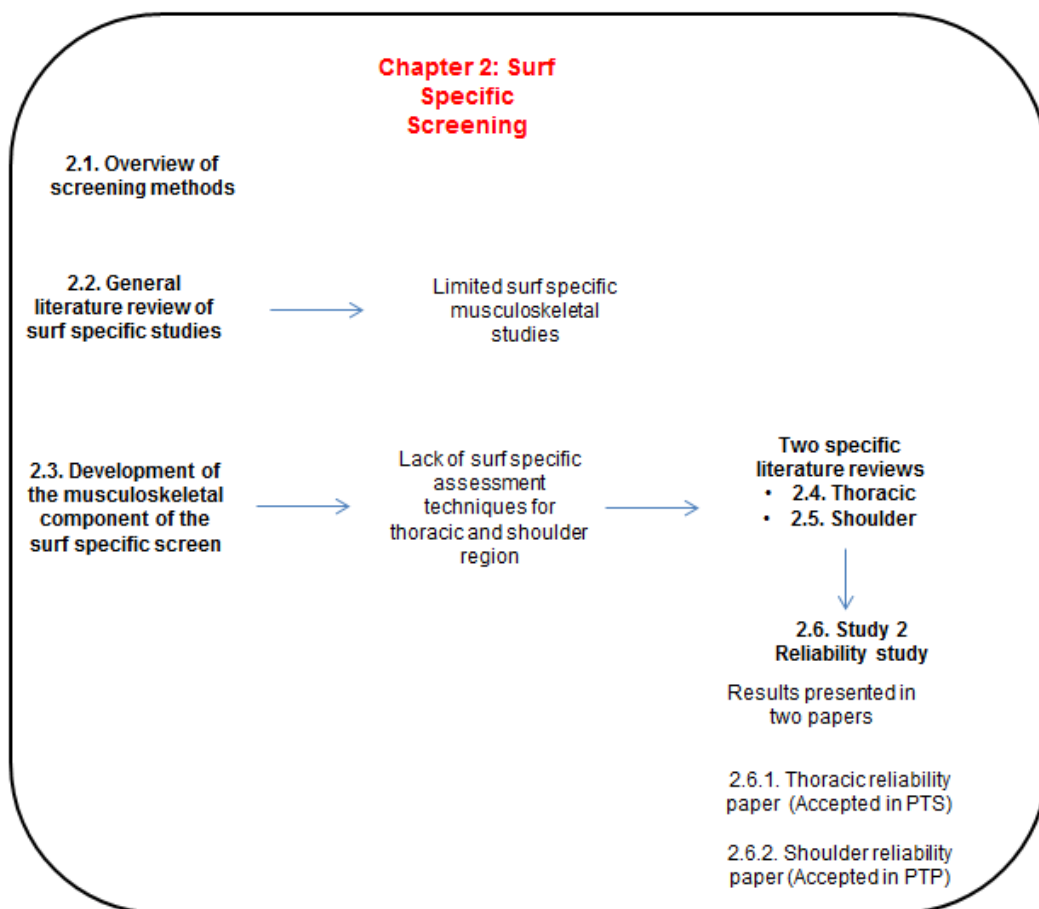


Figure 4: Outline of Chapter 2

2.1. OVERVIEW OF SPORTS SPECIFIC SCREENING METHODS

The demands of a particular sport the athlete participates in will direct the type of sport specific screen which is carried out (Spurrier, 2015). Generally a sports physician will conduct a medical screen and the physical screen will be conducted by the appropriate health professional.

Sports specific screening in its simplest form will involve a subjective and objective assessment. Subjective assessment involves gathering critical information regarding injury history, participation levels and training volumes. Objective assessment commonly involves evaluating the musculoskeletal system of the athlete. Additional testing commonly involves an assessment of body composition, specific fitness/physiological assessment and biomechanical analysis if feasible (Brukner, 2012).

Testing measures should attempt to replicate specific physical and physiological demands of the sport the athlete participates in and must be shown to be reliable and valid (Pelham & Holt, 1995). Figure 5 below illustrates the components within sport specific screening.

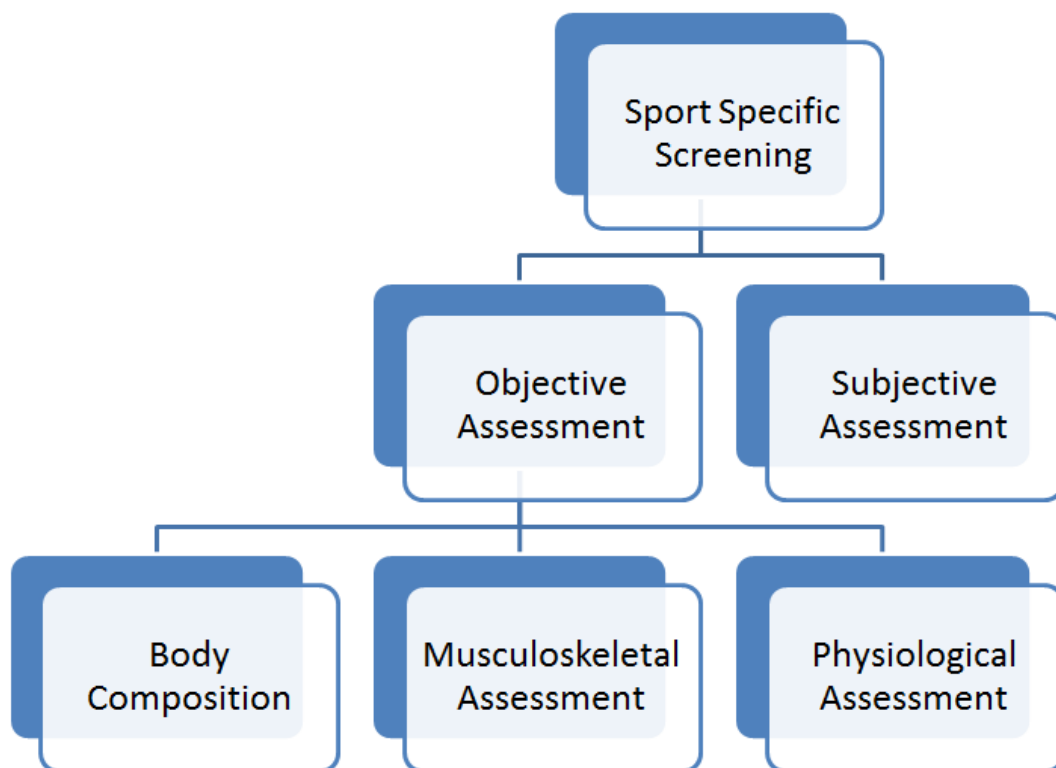


Figure 5: Key Components of Sport Specific Screening

2.2. LITERATURE REVIEW OF SURF SPECIFIC ASSESSMENT AND SCREENING METHODS

2.2.1. Preface

Following on from section 2.1 a general review of surf specific studies that performed subjective and or objective assessment was undertaken.

Due to the limited number of surfing studies, swimming and gymnastics studies were also included in this review. These sports were included due to their parallels with the sport of surfing and to provide further insight into developing a surf specific screen.

This review aimed to address several uses for sports specific screening and gain insight into the current literature specific to surfing. Primarily, it aimed to assist in the design of the surf specific screen.

2.2.2. Introduction

A recent global burden of diseases study by Murray et al. (2012) assessed burden consistently across diseases and identified non-communicable diseases such as musculoskeletal conditions as an emerging global issue. When reviewing the disability component alone (which reflects the pain and suffering associated with a condition) musculoskeletal conditions are the leading cause of disability in Australia. There is currently an emphasis in sport to produce positive health results and maintain high participation levels. With sports medicine, this is accomplished by minimising injury, refining rehabilitation and enhancing performance (Spurrier, 2015). Sport specific screening is often implemented to ensure the above outcomes are achieved.

Therefore, the purpose of this review was to explore assessment/ screening methods used in the sport of surfing, swimming and gymnastics (see further rationale in methods sections for the inclusion of swimming and gymnastics articles). Subsequently this would guide the development of a comprehensive surf specific screen.

2.2.3. Methods

2.2.3.1. Literature Search Strategy

A literature search was conducted using Pubmed, EMBASE, CINAHL, and SPORT-Discuss. The search was limited to articles involving human participants published in English language prior to March 2014. Article titles and their abstracts were screened for relevance and the bibliographies of key articles were reviewed to identify any further relevant articles. Articles were deemed relevant for the literature review if they aimed to screen, assess or profile surfers.

Articles specific to the sport of swimming and gymnastics were also included within this search strategy. The repetitive upper body movements during paddling somewhat parallels the freestyle action during swimming. Although the freestyle movement involved in swimming is not a complete replica of paddling, similarities visually exist. Both paddling and swimming involve alternating arm strokes with a pull and recovery phase and both movements occur in the prone position.

Gymnastics articles were also included in the review as both sports are interspersed with intermittent and explosive lower body and trunk movements. Although no

evidence exists linking gymnastics and the sport of surfing, video-graphic and photographic evidence reveals some of the similarities of the two sports. This has become more evident recently with the new style of surfing that involves aerial manoeuvres. Surfing Australia's High Performance Centre (HPC) also utilize gymnastics as part of their land based training.

Articles specific to swimming or gymnastics were only included if they used a series of tests to screen, assess or profile the athlete. This inclusion criterion was applied to provide greater insight to assist in designing a surf specific screen. The refinement and selection of studies is illustrated in Figure 6.

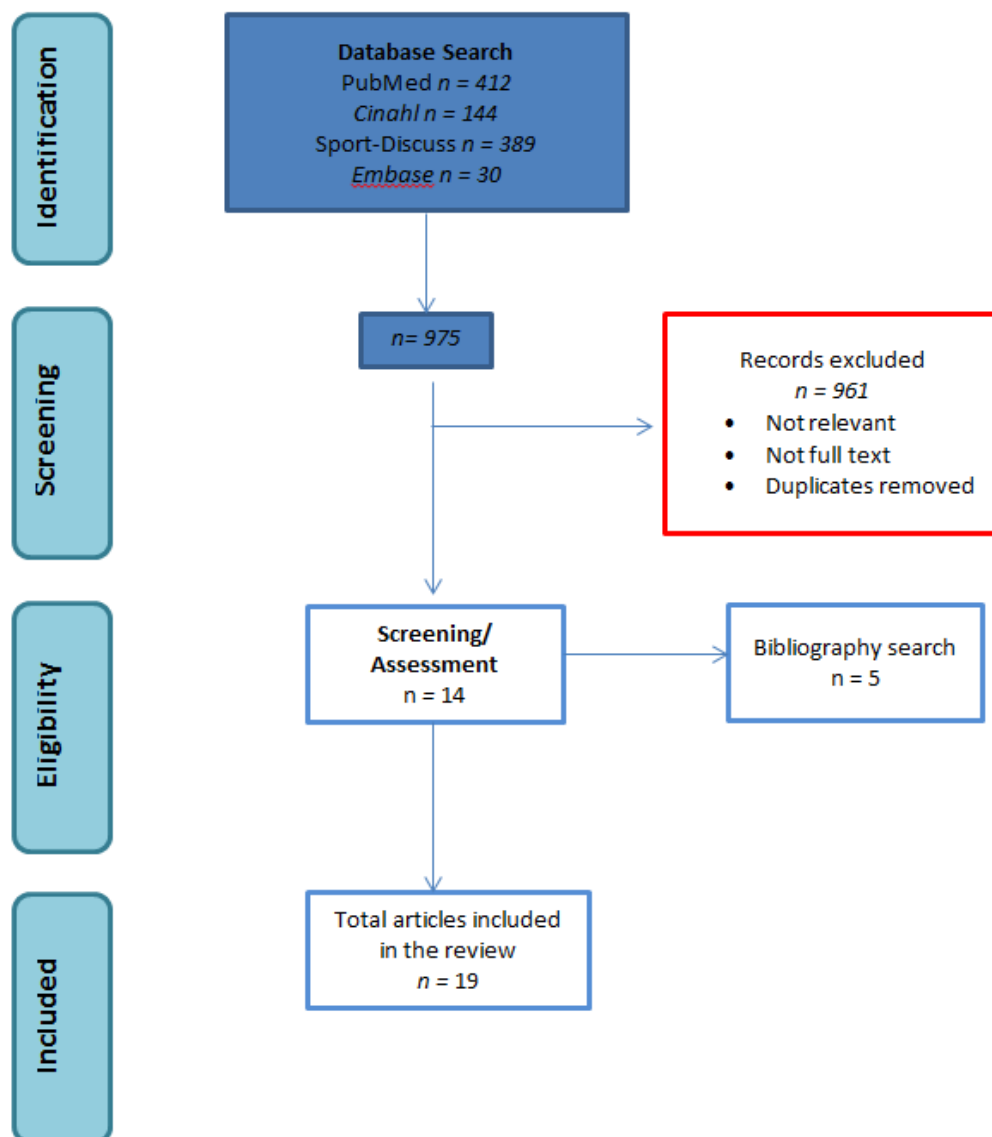


Figure 6: Flow Diagram of Refinement of Articles

2.2.4 Discussion

2.2.4.1 The Aim of Sports Specific Screening

It is well known that exercise training and participation in a sport results in physical and physiological adaptations that results in positive changes in both strength and flexibility (Probst et al., 2007). Conversely sports participation can result in negative adaptations by creating muscle and flexibility asymmetries and therefore increase the risk of developing overuse injuries (Wanivenhaus, Fox, Chaudhury, & Rodeo, 2012). Sport specific screening has become an integral tool to assess for the positive or negative adaptations because of sport participation.

Screening commonly commences with a subjective history followed by a musculoskeletal and or a physiological assessment. A sport specific screen provides an individual profile of the assessed athlete specific to the athletic needs of the specific sport.

The premise behind sports specific screening is three fold; 1) to provide a profile of an athlete; 2) prevent current and further injury through identifying limitations and or asymmetries in joint ROM and or muscular strength and 3) enhance performance (Spurrier, 2015).

2.2.4.2 Predictive Ability of Sports Specific Screening

For a sport specific screen to have an ability to predict injuries a screen must be implemented prior to injuries being sustained. Longitudinal follow up studies are then able to reveal which variables are predictors of injuries. Without this, it is only possible to determine baseline values of the athletic cohort and potentially reveal associations between variables. A study conducted by Kujala, Taimela, Salminen, and Oksanen (1994) conducted low back pain reports and physical measurements in 119 adolescents and revealed that decreased lumbar flexion and hip flexor tightness at baseline were predictive of low back pain among boys during follow up studies. Among girls, higher than average body weight at the baseline measurements and low back pain during the 12 months preceding the baseline measurements were predictive of low back pain during the follow up.

If a screening tool has shown to have predictive ability by identifying risk factors for injuries then prevention strategies can be put in place to combat the risk factors identified.

2.2.4.3 Discriminative Ability of Sports Specific Screening

Selecting tests which are able to discriminate between groups or even discriminate levels of performance may provide valuable information for coaches and clinicians. With respect to surfing, paddling involves upper body aerobic and anaerobic power. Sheppard et al. (2013) implemented a series of tests in a group of competitive international surfers and competitive national surfers. The testing protocol included a sprint paddle, endurance paddle, lower limb power and strength tests and anthropometric assessment. The elite group were significantly ($p < .05$) leaner and stronger and had superior sprint and endurance paddling ability than lower performing competitive surfers, therefore highlighting the ability of these tests to discriminate between groups.

2.2.4.4 Subjective Assessment

Prior to the commencement of a sport specific screen, a subjective history is usually taken. Questions are commonly centred on training volume (both sports specific and non-specific), competitive status, history of participation and injury history (acute and chronic). This information is crucial in identifying a holistic profile of the athlete being screened and can provide relationships of screening outcomes and performance.

In a study by Farley, Harris, and Kilding (2012a) which gathered information on competitive status; revealed a significant correlation ($r = .55$) between season rank and peak power output in elite surfers. A study conducted by Saavedra, Escalante, and Rodriguez (2010) used training volume data to determine a correlation with performance in young elite swimmers.

Injury history may also be correlated with musculoskeletal assessment. A study conducted by Wright and De Crée (1998) revealed a trend where low injury risk subjects (determined in a pre-screening questionnaire) were significantly ($p = .013$) more flexible than high injury risk subjects for lumbar extension and ankle dorsiflexion in female Olympic gymnasts.

2.2.4.5. Objective Assessment: Body Composition

Body composition is commonly estimated with both laboratory and or field equipment with variations in complexity, cost and accuracy (Armstrong, Brubaker, Whaley, & Otto, 2006). Anthropometric measures, which include height, weight, circumferences and skinfolds, appear to be frequently used in the selected studies within this review. This type of information provides a general physical profile of the athlete being assessed.

Table 14 provides a summary of height, weight, arm span and skin fold values in both competitive and recreational surfers. Interestingly surfers heights appear to be shorter compared to other aquatic athletes such as elite swimmers ($M = 183.8$, $SD = 7.1\text{cm}$; $n = 231$) (Mazza et al., 1994). Mazza et al. (1994) also reported the body mass values for elite swimmers ($M = 78.4$, $SD = 7.1\text{kg}$; $n = 231$) which appear to be greater than the body mass values of both competitive and recreational surfers presented in Table 14 with values ranging from 66.8 to 72.2kg.

The assessment of body type may also reveal correlations with performance outcomes. Sheppard et al. (2012) performed anthropometry assessment including height, weight, arm span and skinfold testing on 10 competitive male surfers. Arm span revealed a significant correlation ($r = .77$) with sprint paddle performance over five meters. Wright and De Crée (1998) reported that gymnasts classified as high injury risk were significantly taller and heavier than lower injury risk gymnasts were. Jurimae et al. (2007) used dual-energy X-ray absorptiometry (DEXA) to determine body composition and found a significant correlation between $\text{VO}_{2\text{peak}}$ and body mass ($r = .69$), fat free mass (FFM) ($r = .65$) and bone mineral density ($r = .68$) in competitive junior swimmers. Dual-energy X-ray absorptiometry is widely considered the most accurate, reliable and valid method of assessing body composition (Armstrong et al., 2006).

To our knowledge there is no published study using DEXA to assess body composition in a surfing population. Identifying an athlete's body composition may assist in determining performance, injury risk factors, baseline levels and improvements following an intervention.

Table 14: Body Type Characteristics in a Surfing Population

	Study	Competitive level, sample size, age*	Height (cm)*	Weight (kg)*	Arm Span (cm)*	Skin fold assessment*
Competitive surfers	Sheppard et al. (2012)	International, $n = 10$, 23.9 ± 6.8 years	177.0 ± 6.5	72.2 ± 2.4	-	-
	Farley et al. (2012a)	National, $n = 8$; 20.6 ± 6.6 years	181.4 ± 7.8	71.1 ± 11.2	-	-
	Loveless and Minahan (2010a)	Junior, $n = 8$; 18 ± 1 years	172 ± 0.1	68.0 ± 11.7	175.8 ± 13.6	-
	Méndez-Villanueva et al. (2005)	European, $n = 7$; 25.6 ± 3.4 years	172.1 ± 4.9	67.0 ± 4.3	-	Skinfolds (sum of six sites) = 47.6 ± 7.3
		Regional, $n = 6$, 26.5 ± 3.6 years)	174.9 ± 4.7	71.1 ± 2.6	-	Skinfolds (sum of six sites) = 46.5 ± 15.4
	Lowdon, Bedi, and Horvath (1989)	College, $n = 12$, 21 ± 1 years)	177.7 ± 7.2	70.5 ± 5.1	-	-
Recreational surfers	Loveless and Minahan (2010a)	$n = 8$; 18 ± 2 years	175 ± 0.1	66.8 ± 13.0	179 ± 11.0	-
	Meir et al. (1991)	$n = 6$; 21.2 ± 2.8 years	175.8 ± 5.53	68.9 ± 5.67	-	Skinfolds (sum of all four sites) = 33.4 ± 10.1

*Means and standard deviations (\pm) are presented

2.2.4.6 Objective Assessment: Musculoskeletal Examination

2.2.4.6.1 Range of Motion Assessment

Athletes are commonly assessed to determine ROM at specific joints. This provides baseline values, detects asymmetry, assists in diagnosing pathology and helps provide a profile of the athlete. A lack of flexibility is commonly linked with injury and hence the rationale for being included in a sports specific screen (Probst et al., 2007).

Each sport has different requirements on various joints; therefore sports specific screening needs to assess ROM in the joints which are under stress and or prone to injury (O'Connor et al., 2013). The sport of surfing has unique requirements; when paddling the shoulders and upper spine are subject to stress; however when standing and actually riding the wave, the lower spine and lower limbs are under strain (Everline, 2007). One would assume that ROM would need to be assessed in key regions of both the lower and upper body. Surprisingly no published research was identified which assessed ROM within a surfing population.

As the sport of swimming has large requirements for the thorax and shoulders, ROM at these regions is specifically assessed within sport specific screening. Saavedra et al. (2010) assessed maximum shoulder flexion and extension in elite swimmers in sport specific positions obtained from video graphic evidence. Geladas, Nassis, and Pavlicevic (2005) assessed shoulder extension and ankle dorsiflexion as part of a comprehensive battery of tests in elite swimmers, the specific position however was not reported.

Range of motion assessment in the sport of gymnastics appears to address the lower body and lumbar spine more extensively. A study conducted by Douda, Toubekis, Avloniti, and Tokmakidis (2008) performed a sit and reach test and a series of gymnastic specific hip movements. A study which assessed ROM in 14 gymnasts used a flexi-curve to assess lumbar extension and flexion; modified schobers test to also assess lumbar flexion and hamstring and hip flexor length (Kujala et al., 1994). Wright and De Crée (1998) categorised gymnasts as either low or high risk of sustaining an injury through the use of a validated questionnaire. The gymnasts who were categorized as low risk revealed significantly better flexibility scores (back extension and ankle dorsiflexion). Although the lack of flexibility/ ROM cannot be considered a direct cause of high injury risk, associations and trends can be seen.

Establishing these trends provides a foundation for further studies involving long-term follow up to truly reveal cause and effect.

As previously mentioned, no published studies were identified in this literature search that assessed ROM in a surfing population. ROM testing in the joints, which are under stress and or prone to injury, needs to be conducted in a surfing population. This will provide normative data, potentially identify adaptations as a result of surfing and identify possible relationships between injuries and or performance.

2.2.4.6.2 Strength Assessment

Muscular strength assessment of an athlete can assist with identifying baseline strength values for a particular athletic group, identify muscle imbalance, assist in identifying pathology and be used as a performance indicator (Dollings, Sandford, O'Conaire, & Lewis, 2012). Currently there is limited evidence regarding strength testing within the sport of surfing. A study conducted by Sheppard et al. (2012) assessed 10 competitive male surfers upper body pulling strength (1RM pronated pull up) and the association with paddle performance from a stationary start over 15m. A strong positive association ($r = .88$) was found between relative upper body pulling strength and sprint paddling time over 15m.

Baron, Petschnig, Bachl, Engel, and Ammer (1990) compared quadriceps strength in a surfing population to 15 untrained males. The surfing group had no history of extensive strength training and a history of more than 10 years of surfing. Using isokinetic dynamometry concentric peak torque of knee extensors was measured every 10 degrees between 90 to 20 degrees. The surfer group body weight related strength was higher than the untrained group (3.2 Nm/kg vs. 2.7 Nm/kg respectively). Surfers revealed greater quadriceps strength despite the absence of strength training suggesting that lower body strength adaptations occur because of surfing. Sheppard et al. (2013) assessed lower limb strength and power using a counter movement jump test and a isometric mid-thigh pull test and found elite surfers possessed higher lower body isometric peak force compared to age matched competitive surfers.

Core strength has been assessed in surfers using a seven level abdominal strength test and surprisingly surfers scored below average when compared with age match cricket netball and soccer athletes (Plag et al., 1999). Coopoo and Patterson (2001) assessed 61 elite South African surfers shoulder internal and external rotation

strength using isokinetic dynamometry. Results revealed lower mean peak torque values in shoulder external rotators ($M = 32.53$, $SD = 8.81\text{Nm}$) compared with shoulder internal rotators ($M = 59.96$, $SD = 13.22\text{Nm}$).

A study conducted by Dummer, Vaccaro, and Clarke (1985) on masters swimmers assessed strength at the shoulder and knees due to the upper and lower body requirements during the freestyle action. Strength was assessed using an isokinetic dynamometer; however the position utilized to assess strength was not sport specific. A study conducted by Evershed, Burkett, and Mellifont (2014) also used an isokinetic dynamometer to measure internal and external rotation in both a sitting and supine position for nationally ranked swimmers. An isokinetic dynamometer is considered the gold standard in quantifying muscular strength as the angle and speed of contraction can be controlled. These machines however are costly and not clinically appropriate, questioning the ability to incorporate this form of assessment in a sports specific screen.

In the sport of gymnastics, lumbar endurance tests are commonly included in sports specific screening. Elite gymnasts have higher numbers of anatomic abnormalities of the lumbar spine compared with non-athletes (Kujala et al., 1994). Disk degeneration has been associated with vertebral end plate changes in young gymnasts and changes have correlated with symptoms (Tertti et al., 1990). McGill, Melanie, Crosby, and Russell (2010) revealed that poor lumbar muscular endurance has been associated with back pain. This therefore validates the use of muscular endurance testing in the lumbar spine.

Douda et al. (2008) used a sit-ups test, where by gymnasts performed a maximal number of sit-ups in 30 seconds with both legs flexed to 90 degrees. Kujala et al. (1994) used an abdominal test, where by the gymnasts were asked to curl up and hold this position for a maximum of 240 seconds. Lumbar extensor strength was assessed with the gymnasts lying prone and the upper body off the examination table; subjects were then asked to hold the upper body and head horizontal for a maximum of 240 seconds. Currently limited published studies exist which assess muscular strength in a surfing population. Assessment of muscular strength at joints which are under stress or prone to injury needs to be conducted.

With the current limited number of surfing studies pertaining to strength testing there is no one region of focus; two studies assessed the shoulder, one study assessed the lower limb and one study assessed core endurance. With regards to musculoskeletal screening in swimming there tends to be a focus around the shoulder and thoracic

region; however, musculoskeletal screening in gymnastics tends to focus around the trunk and lower body. As previously mentioned surfing incorporates similar movements to the aforementioned sports; therefore the musculoskeletal component of a surf specific screen would adopt a combination of both screens; Figure 7 presents this concept. This will capture the multiple joints used within surfing and provide baseline data, potentially identify adaptations because of surfing and identify possible relationships between injuries and or performance.

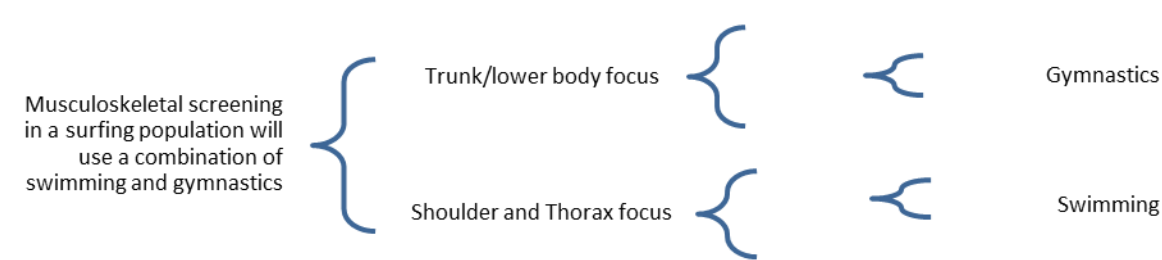


Figure 7: Development of the Musculoskeletal Portion of the Surf Specific Screen

2.2.4.7 Objective Assessment: Physiological Testing

2.2.4.7.1 Aerobic Testing

This literature search identified several studies that assessed the physiological system in the sport of surfing. Time motion analysis revealed that upper body aerobic paddling represents the largest component of surfing (Mendez-Villanueva & Bishop, 2005). Meir et al. (1991) further quantified this through revealing that during a one-hour recreational surfing session the mean heart rates when paddling represented 80% of the laboratory peak heart. Laboratory peak heart rates were attained through a progressive swim bench ergometer peak oxygen uptake test (VO_{2peak}). This further reinforces the aerobic demands of surfing.

Aerobic fitness is commonly assessed through a maximal volume uptake test (VO_{2max} test). VO_{2max} testing is recognized as the gold standard physiological indicator of maximal aerobic power with test retest reliability high ($r = .95-.99$) (Adams & Beam, 2008). It is the maximum capacity of an individual's body to transport and use oxygen during incremental exercise, which reflects the physical fitness of the individual.

VO_{2max} testing has been extensively performed on a number of sports and more recently with both recreational and competitive surfers. A number of modalities have been used with differing testing protocols. These modalities have included treadmill, tethered board paddling, hand crank ergometer (Lowdon et al., 1989), bicycle ergometer (Lowdon, 1980), and more recently on both swim bench and kayak ergometers (Farley et al., 2012a; Loveless & Minahan, 2010b). Overall surfers (competitive and recreational) have illustrated high levels of aerobic fitness with VO_{2peak} scores ranging from 40-70 ml/kg/min (Loveless & Minahan, 2010a; Lowdon et al., 1989; Méndez-Villanueva et al., 2005).

Lowdon et al. (1989) compared treadmill running with tethered board paddling and prone arm cranking on 12 male competitive college surfers. Similar physiological VO_{2peak} values were found between the tethered board paddling and prone arm cranking ($M = 40.4$, $SD = 2.9$ and $M = 41.6$, $SD 4.0$ ml/kg/min respectively). Meir et al. (1991) estimated VO_{2peak} scores through submaximal testing using a swim bench prone arm paddling protocol on six recreational surfers and revealed higher VO_{2peak} values ($M = 54.20$, $SD = 10.2$ ml/kg/min) than earlier research by Lowdon et al. (1989). Méndez-Villanueva et al. (2005) used a modified kayak ergometer and

revealed similar results with competitive European level surfers ($M = 50.0$, $SD = 4.67$ ml/kg/min) and competitive regional surfers ($M = 47.93$, $SD = 6.28$ ml/kg/min).

The two most recent studies used ergometers with the surfer tested in the prone position and simulating a paddling technique (Farley et al., 2012a; Loveless & Minahan, 2010a). Loveless and Minahan (2010a) used a swim bench ergometer to assess peak oxygen uptake and paddling efficiency in both competitive and recreational surfers and found no significant differences between both groups. The VO_{2peak} scores for the competitive group ($M = 39.5$, $SD = 3.1$ ml/kg/min) and the recreational group ($M = 37.8$, $SD = 4.5$) were also lower than previous research.

Farley et al. (2012a) assessed peak oxygen uptake ($M = 44.0$, $SD = 8.26$ ml/kg/min) of eight nationally ranked surfers on a modified kayak ergometer. No significant relationship was found between peak oxygen uptake and season rank. Both studies revealed no relationship of peak oxygen uptake to performance with both authors concluding that peak oxygen uptake is not a determinant of performance. However, results continue to show moderate to high levels of peak oxygen uptake, especially when compared to other endurance sports. It also needs to be mentioned that despite surfers adopting a prone position (which has shown to alter haemodynamic and performance parameters) mean VO_{2peak} values were 20% higher when compared with an active young male population tested with seated arm ergometry (Mendez-Villanueva & Bishop, 2005). This continues to illustrate the physiological adaptations occurring with participation in the sport of surfing.

The range of peak oxygen uptake scores in the outlined research may be due to differences in testing modalities, protocols used, change in increments, and lack of large sample sizes. Research strongly supports specificity when performing fitness assessments and therefore using a swim bench with a paddling style is most appropriate (Armstrong et al., 2006). Future research would therefore need to involve a prone position with a paddling technique using a well-validated protocol with a larger sample size. Surprisingly anaerobic threshold has not been investigated through VO_{2max} testing on a swim bench ergometer with a surfing population. Surfing involves repetitive high intensity paddling bouts and an ability to maintain a higher power output without the production of lactate may be a desirable attribute. Therefore future studies should look to investigate anaerobic threshold as a determinant of performance.

2.2.4.7.2 Anaerobic Testing

One way of evaluating maximal-intensity exercise is to measure external power output. Swim bench ergometry has been shown to be reliable when testing aquatic athletes such as surf life savers (Morton & Gustin, 1997) and swimmers (Swaine, 2000), and more recently with recreational and competitive surfers (Loveless & Minahan, 2010b). Loveless who performed six trials of maximal intensity paddling concluded that swim bench ergometry is both reliable between trials but also on separate days of testing ($r = .98$).

Not only have swim bench ergometers proven to be reliable they have also proven to be valid tools in assessing performance. Research with swimmers has shown high correlations between power output and swimming velocities conducted in a pool (Rohrs, Mayhew, Arabas, & Shelton, 1990). Farley et al. (2012a) assessed maximal power output of 20 male nationally ranked competitive surfers on a modified Kayak ergometer. Results revealed a significant relationship between anaerobic power and season rank ($r = .55$).

Currently swim bench ergometers are the most sport-specific devices available for surfboard paddling. To date, only two studies (Farley et al., 2012a; Loveless & Minahan, 2010a) have used ergometer's to assess power output specifically in a surfing population. Although swim bench ergometry has been shown to be both reliable and valid, discrepancies still remain between both of these studies which have assessed power output in surfers. Loveless and Minahan (2010b) revealed mean power outputs of 11 male junior competitive surfers to be 348 (78) watts which is higher than both competitive swimmers ($M = 304$, $SD = 22W$) and surf lifesavers ($M = 326$, $SD = 29W$) (Morton & Gustin, 1997; Swaine, 2000). Not only do these values exceed other water based sports they are also higher than the more recent study conducted by Farley et al. (2012a) who performed the same test however on a Kayak ergometer. Mean peak anaerobic power in 20 nationally ranked surfers was 205 ($SD = 54.2$) watts.

The lack of surf specific studies and the identified discrepancies warrant the need for further maximal exercise testing using swim bench ergometry. A summary of aerobic and anaerobic findings specific to a surfing population is seen in Table 15.

Table 15: Reviewed Literature Involving Aerobic and Anaerobic Surf Specific Testing

	Study	Subjects (competitive level, sample size, age)*	Testing mode	VO2 peak (ml/kg/min)*	Peak aerobic power*	Absolute peak anaerobic power (W)*	Relative anaerobic power (W/kg)*
Competitive surfers	Farley et al. (2012a)	National level, n = 8; 20.6 ± 6.6 years	Modified kayak ergometer	44 ± 8.3	158 ± 20.7	205 ± 54.2	2.83 ± 0.66
	Loveless and Minahan (2010a)	Junior level, n = 8; 18 ± 1 years	Swim bench ergometer	39.5 ± 3.1	199 ± 45	348 ± 78 (n = 11)	-
	Méndez-Villanueva et al. (2005)	European level (n = 7; 25.6 ± 3.4 years)	Modified kayak ergometer	50.0 ± 4.7	154 ± 37	-	-
		Regional level (n = 6, 26.5 ± 3.6 years)	Modified kayak ergometer	47.9 ± 6.3	118 ± 27	-	-
	Lowdon et al. (1989)	College level (n = 12, 21 ± 1 years)	Treadmill Tethered board paddling Arm crank ergometry	56.3 ± 3.9 40.4 ± 2.9 41.6 ± 4.0	-	-	-
Recreational surfers	Loveless and Minahan (2010a)	n = 8; 18 ± 2 years	Swim bench ergometer	37.8 ± 4.5	199 ± 24	-	-
	Meir et al. (1991)	n = 6; 21.2 ± 2.8 years	Swim bench	54.2 ± 10.2		-	-

*Means and standard deviations (±) are presented

2.2.4.7.3 Field Based Testing

This literature review revealed only two surf specific studies that performed anaerobic and aerobic power testing with a field based test (in a swimming pool). Loveless and Minahan (2010b) performed a 10-second maximal intensity paddle on surfers' personal surfboard in a 25-meter swimming pool. No differences existed between the laboratory tests and the field tests, indicating the use of either for anaerobic testing. Sheppard et al. (2013) assessed sprint paddle ability in a pool over a 15m distance. Endurance was also assessed over a 400m distance. Both forms of testing were able to discriminate between groups of differing skill levels.

A comparison of aerobic lab and field based testing is yet to be conducted in surfing population. This would indicate if both forms of testing could be used to determine aerobic fitness. With access to lab equipment not being feasible for many coaches and clinicians, simple field based tests may be more appropriate.

2.2.4.7.4 Lactate Testing

Under normal resting conditions, lactic acid is metabolized to CO_2 and therefore does not affect pH homeostasis. However heavy exercise can result in large amounts of lactic acid due to the contracting skeletal muscle, this is known as exercising above the lactate threshold. Lactic acid both hinders the ability of skeletal muscle to contract and reduces the muscle cell's ability to produce ATP by inhibiting key enzymes involved in both aerobic and anaerobic production of ATP. Once produced in the body it rapidly ionizes by releasing a hydrogen ion and becomes the molecule known as lactate (Powers & Howley, 2012).

This literature search revealed two studies that investigated the production of lactate during aerobic testing in a surfing population. Research conducted by Méndez-Villanueva et al. (2005) used an incremental ramp test with four, three minute work stages followed by a 20 watt increase every 30 seconds until volitional exhaustion. Lactate samples were taken at each work stage and at one, three and five minutes post-test. $\text{VO}_{2\text{peak}}$ scores did not differ between the recreational and the professionals, however peak aerobic power was significantly ($p = .02$) different and the professional group reached their lactate threshold (4 mmol/L) at a higher percentage of their $\text{VO}_{2\text{peak}}$ than the recreational group ($M = 95.18$, $SD = 3.42$ vs. $M = 88.89$, $SD = 5.01$ % $\text{VO}_{2\text{peak}}$, respectively). Loveless and Minahan (2010a) also used

an incremental ramp test with lactate samples taken at four, three-minute work stages as well as at one and 3-minutes post exercise. Blood lactate concentration was significantly greater ($p = .04$) in the recreational group in the final work stage compared with the competitive group. Peak lactate did not differ between recreational and competitive groups post exercise.

Attaining peak blood lactate post testing and ensuring it is above 8.0 mmol/L helps determine that the exercise was a sufficient intensity and poor subject motivation can be ruled out (Armstrong et al., 2006). With a limited number of surf specific studies reporting lactate sampling it would be advantageous to include lactate testing during aerobic testing.

2.2.4.8. Determining the Assessment Components within a Sport Specific Screen

This review has presented the key components that are commonly found in sport specific screening. Table 16 presents the four components including subjective history, body composition, musculoskeletal and physiological assessment. The completion of these components provides a comprehensive profile of the athlete. The studies that included a surfing population tended to have more emphasis on physiological assessment. The swimming studies tended to have a mixed approach using either musculoskeletal assessment or physiological assessment and the gymnastics based studies had more of a musculoskeletal emphasis. The possible reasoning may be that either form of assessment may be out of the researcher scope. Another reason may be that musculoskeletal assessment generally has an injury prevention focus whereas physiological assessment is usually conducted to determine performance levels.

Considering the demands on the musculoskeletal system and the aerobic and anaerobic requirements involved in surfing, a surf specific screen needs to involve both musculoskeletal and physiological assessment. Using a surf specific screen with all four components of assessment (subjective history, body composition, musculoskeletal and physiological assessment) may provide a comprehensive profile of the athlete and enable a holistic approach to exercise prescription.

Table 16: Four Key Components in a Sports Specific Screen

Author	Sport	Subjective history (S)	Body composition assessment (BC)	Musculoskeletal Assessment (M)	Physiological Assessment (P)	S, BC, M, P (were all 4 included)
(Sheppard et al., 2013)	Surfing	√	√	√	√	√
(Sheppard et al., 2012)	Surfing	X	√	√	√	No (BC,M,P)
(Farley et al., 2012a)	Surfing	√	√	X	√	No (S,BC,P)
(Loveless & Minahan, 2010b)	Surfing	√	√	X	√	No (S,BC,P)
(Loveless & Minahan, 2010a)	Surfing	√	√	X	√	No (S,BC,P)
(Méndez-Villanueva et al., 2005)	Surfing	√	√	X	√	No (S,BC,P)
(Meir et al., 1991)	Surfing	√	√	X	√	No (S,BC,P)
(Lowdon et al., 1989)	Surfing	√	√	X	√	No (S,BC,P)
(Evershed et al., 2014)	Swimming	√	X	√	√	No (S,M,P)
(Saavedra et al., 2010)	Swimming	√	√	√	√	√
(Jurimae et al., 2007)	Swimming	√	√	X	√	No (S,BC,P)
(VanHeest, Mahoney, & Herr, 2004)	Swimming	X	√	X	√	No (S,BC,P)
(Dummer et al., 1985)	Swimming	X	√	√	X	No (BC,M)
(Douda et al., 2008)	Gymnastics	X	√	√	√	No (BC,M,P)
(Wright & De Créé, 1998)	Gymnastics	√	√	√	X	No (S,BC,M)
(Kujala et al., 1994)	Gymnastics	√	√	√	X	No (S,BC,M)

√ refers to testing included; X refers to testing not included

Note: Red refers to majority of surf specific literature not including musculoskeletal assessment

2.2.5 Recommendations for the Development of a Surf Specific Screen

Several key recommendations have been identified following this review.

- A sport specific screen needs to commence with a subjective history including surfing history, competitive status and injury history (acute and chronic).
- Body composition assessment needs to be included in a screen along with simple anthropometric measures (height, weight, arm span). DEXA is considered the gold standard in assessing body composition and should be utilized to determine body composition.
- ROM and muscular strength testing in the joints which are under stress and or prone to injury needs to be conducted in a surfing population.
- Physiological assessment within a surfing population should utilize already established methodologies for aerobic and anaerobic testing. This should be conducted on a swim bench ergometer as this is currently the most specific and reliable method. As aerobic testing is yet to determine discrepancies in performance this needs to be done with a large sample size in both a recreational and competitive cohort.
- A surf specific screen needs to involve all four components; subjective history, body composition, musculoskeletal and physiological assessment. This will truly provide a comprehensive profile of a surfing cohort; identify adaptations as a result of surfing and provide key information to clinicians to potentially decrease the occurrence of injury and enhance performance.
- No study identified within this review utilized a biomechanical assessment as part of a screening or profiling process. Nonetheless, biomechanical assessment would be a useful tool to understand paddling requirements. Due to the feasibility of conducting such research this will not be pursued within this thesis.

2.2.6 Conclusion

This narrative literature review has identified key recommendations for the development of a surf specific screen. It has acknowledged the need to address all four components within a sport specific screen (subjective history, body composition, musculoskeletal and physiological testing).

There is a clear lack of musculoskeletal assessment in the sport of surfing and this area needs to be included. It is imperative that the tests selected within the musculoskeletal component of the surf specific screen are reliable and specific to the sport of surfing.

Physiological assessment within a surfing population should utilize already established methodologies for aerobic and anaerobic testing utilizing a swim bench ergometer as this is currently the most specific and reliable method. Body composition assessment with DEXA should also be included in a screen. These studies need to be conducted in larger sample sizes in order to generalise results to a surfing cohort.

2.3 DEVELOPMENT OF THE MUSCULOSKELETAL COMPONENT FOR THE SURF SPECIFIC SCREEN

Following on from section 2.2, the literature review revealed that the majority of surf specific studies did not include musculoskeletal assessment. Using the recommendations from the review of screening methods (section 2.2) and the findings from Chapter 1, specific tests have been selected for the musculoskeletal component of the surf specific screen (see Table 17 which presents the rationale of the selected tests within the surf specific screen). Table 17 highlights two areas (shoulder and thoracic region) which require further review of the literature to identify surf specific clinical techniques. Consequently, section 2.4 presents individual literature reviews, which systematically analyse and critique the current literature for both of these regions. Both of these reviews were completed to determine whether the development of new surf specific tests was needed.

When deciding which tests to include and in what regions, five key questions needed to be answered.

1. Are the tests specific to surfing?
2. Do these tests assess the key joints under stress or injury prone locations?
3. Have the tests been proven in the literature to be reliable?
4. Are these tests time efficient and able to be performed with equipment that is accessible in clinical practice?
5. Do the tests have normative data to compare against?

Table 17: Rationale of Tests Included in the Musculoskeletal Component of the Surf Specific Screen

Range of Motion	Test	Procedure	Specificity	Key joints under stress or injury prone locations	Reliability	Clinical application	Normative data
	Cervical spine extension and rotation	Surfer is sitting and CROM brace is applied. Cervical extension flexion and rotation is measured.	These movements are critical when paddling in a prone position.	Chapter 1 of this project showed neck injuries to represent 9.2% of acute injuries and 9.6% of all chronic surfing injuries.	Yes, ICC's ranged from .89-.98 for intra-rater reliability (Audette, Dumas, Cote, & De Serres, 2010).	Yes	Yes
	Thoracic spine extension and rotation	To be determine following literature review.	Thoracic extension is crucial to maintain the head in an upright position and ensure good arm clearance when paddling. Thoracic rotation is needed during turning movements.	Although this was not considered a frequently injured region, thoracic extension and rotation are key movements and these regions are under stress when both paddling and performing turning maneuvers.	To be determined through literature review.	To be determined	To be determined
	Static thoracic kyphosis	Surfer is standing in a relaxed posture and the angle at T1/2 and T12/L1 are added together to give the kyphosis angle.	An ability to extend through the thoracic spine is crucial when lying prone paddling. Excessive kyphosis would limit this.	Thoracic region is under stress during the paddling.	Yes, ICC's have ranged from .97-.99 for intra-rater reliability (Lewis & Valentine, 2010)	Yes	Yes
	Lumbar flexion and extension	Surfer is in standing, Modified-Modified Schobers test will be used to assess lumbar flexion. Prone extension with the pelvis stabilized will be used to assess lumbar extension	Lumbar flexion occurs during turning maneuvers. Lumbar extension occurs during paddling.	Chapter 1 of this project showed the lumbar spine was the most common chronic injury representing 23.2% of all major injuries.	Yes, modified-modified schobers; ICC's have ranged from .89-.97 for intra-rater and .83-.96 for inter-rater reliability (Tousignant, Poulin, Marchand, Viau, & Place, 2005). Prone extension; ICC's ranged from .82-.91 for intra and inter rater reliability.	Yes	Yes
	Prone Shoulder ER and IR	To be determined following literature review.	Prone is the position the surfer is in when paddling.	Chapter 1 revealed the shoulder to be the most frequent acute injury (16.4) and second highest frequency for chronic injuries (22.4%).	To be determined following literature review.	To be determined	To be determined

e of Motio	Test	Procedure	Specificity	Key joints under stress or injury prone locations	Reliability	Clinical application	Normative data
	Shoulder Flexion	Surfer is in supine and actively extends arm, shoulder flexion/ latissimus dorsi length is assessed.	Latissimus dorsi is considered a dominant muscle used during paddling.	High shoulder injuries identified in Chapter 1 and the demands of paddling may affect the latissimus dorsi length.	Yes, ICC's have ranged from .64 - .69 for inter-rater reliability (Szomor, Hayes, Murrell, & Walton, 2001)	Yes	Yes
	Hip IR and ER	Surfer is in sitting and maximally rotates the hip.	Hip IR and ER are common movements occurring when riding a wave.	A lack of movement in the hip may predispose other joints to stressed (knee).	Yes, ICC's have ranged from .76 - .98 for inter-tester reliability.	Yes	Yes
	Ankle DF	Surfer flexes ankle so the knee can make contact with the wall.	Ankle DF is crucial when actually riding the wave.	Chapter 1 revealed ankle injuries to be the third most frequent acute injury (14.6%).	Yes, ICC's have ranged from 0.97-0.99 for inter and intra-rater reliability (Bennell et al., 1998).	Yes	Yes
Strength Assessment	Shoulder ER and IR strength testing	HHD used to assess strength in supine lying for shoulder ER and prone lying to assess shoulder IR. The shoulder and elbow were place in 90 degrees of abduction and flexion respectively.	Shoulder ER and IR strength is crucial when paddling. This test position tried to simulate a similar position when paddling.	Chapter 1 revealed the shoulder region to be the most frequent acute injury and second highest chronic injury.	Yes, ICC's ranged from .74 - .98 (Dollings et al., 2012) for intra-rater reliability; however this was not determined in the same position as outline in the test explanation.	Yes	No
	Lumbar endurance	Side bridge and Biering-Sorenson tests were used to determine lumbar muscular endurance.	Rotational and extension strength are crucial when paddling and performing turning movements.	Chapter 1 revealed the lumbar spine to have the highest frequency of chronic injuries. Poor lumbar muscular endurance has been associated with back injury.	Yes, ICC's have ranged from .77 - .88 for intra-rater reliability (Latimer, Maher, Refshauge, & Colaco, 1999).	Yes	Yes
	Lower extremity functional test	The surfer performs a single knee bend and is scored using two visual rating methods (overall and segmental).	This test assesses stability in the lower limb, especially the knee region. Stability is needed when riding a wave.	Chapter 1 revealed the knee region to have the third high frequency for chronic injury. As a lack of stability is associated with knee injuries this test is included.	Yes, slight to almost perfect intra-rater agreement and fair to good inter-rater agreement (Whatman, Hing, & Hume, 2012).	Yes	Yes

2.4. THORACIC MOBILITY; EXTENSION AND ROTATION: A SYSTEMATIC REVIEW OF CLINICAL ASSESSMENT METHODS

2.4.1. Preface

Following on from section 2.3, no specific thoracic ROM test for thoracic extension and rotation were identified to incorporate in the musculoskeletal component of the surf specific screen. Therefore, a review of the current range of motion tests for the thoracic region is presented in the following section. The nature of this review was systematic in order to provide a thorough critique of the current literature.

2.4.2. Introduction

The measurement of thoracic spine range of motion (ROM) appears to be under investigated; this may be attributed to the difficulty of truly quantifying ROM and the questionable relevance of thoracic movement in most mainstream sports (Kuo, Tully, & Galea, 2009). Physiotherapists routinely perform musculoskeletal screening of athletes to determine if limitations in ROM or asymmetries exist and provide rehabilitation exercises to correct these deficits (Spurrier, 2015). This may ultimately enhance performance and potentially reduce the incidence of injury. An attempt is normally made to ensure screening measures are specific to the sport the athlete participates in; however methods used must be standardised and shown to be reliable and valid (Spurrier, 2015). It is deemed appropriate that athletes whose sports involve a significant amount of stress on the thoracic spine, an adequate clinical method is needed for therapists to assess this region.

Using the sport of surfing as an example, the thoracic spine is a key region which is stressed in the sagittal and horizontal planes. The sport of surfing can be broken down into three key phases; paddling (~45% of the time), sitting (~50% of the time) and actual wave riding (~5% of the time) (Meir et al., 1991). During paddling the thoracic spine must be held in a prolonged extended position to allow for adequate arm clearance from the water (Everline, 2007). It is hypothesised that a reduction in thoracic extension during paddling could potentially result in greater stress on the lumbar spine or cervical spine. It could also result in greater shoulder abduction and extension to clear the water, increasing risk of subacromial impingement. During actual wave riding, thoracic rotation is a critical movement to assist in producing torque during turning manoeuvres (Everline, 2007). The surfer rotates towards the wave during the bottom turn and away from the wave during the top turn. It is hypothesised that during these movements the thoracic spine also flexes during the bottom turn and extends during the top turn; a combination of thoracic mobility and strength is therefore required.

When designing a sport specific screening method, it is imperative to look at key injury prone regions and specific joints that are under stress during the activity (Vanmechelen et al., 1992). Chapter 1 of this thesis revealed the two key areas with the highest frequency of chronic injury in the sport of surfing were the shoulder (22.4%) and lumbar spine (23.2%); the thoracic spine could clearly be a contributing factor to both of these regions. Reduced thoracic mobility has been associated with increased cervical and lumbar pain (O'Gorman & Jull, 1987) and shoulder pathology

(Lewis & Valentine, 2010). Treatment directed at the thoracic spine has been associated with improvements in a range of musculoskeletal conditions including cervical and shoulder pathologies (Iveson, McLaughlin, Todd, & Gerber, 2010). An inability to attribute these findings to improvements in thoracic ROM may be due to the lack of feasible and reliable clinical methods to quantify thoracic ROM (Iveson et al., 2010).

It could be proposed that the poor thoracic extension or excessive kyphosis during paddling could cause the scapular to be protracted and downwardly rotated leading to potential compression of the subacromial tissues (subacromial bursa and rotator cuff tendons). This could also result in compensatory cervical extension or lumbar extension while paddling. It could also be proposed that a surfer requires adequate thoracic rotation to achieve the desired torque during turning manoeuvres; inadequate thoracic rotation may result in the surfer placing greater rotational stress at the lumbar spine. Therefore, simple screening measures to assess thoracic mobility in the sagittal and horizontal planes could potentially rule in or out the thoracic region as a possible contributor.

Currently several methods exist which aim to quantify thoracic ROM. These include invasive methods such as X-ray, however this exposes the subject to radiation (~50 microsieverts). Less invasive methods such as inclinometers (Johnson, Kim, Yu, Saliba, & Grindstaff, 2012; O'Gorman & Jull, 1987), goniometry (Johnson et al., 2012), skin surface equipment (Troke, Moore, & Cheek, 1998), tape measures or skin distraction methods (Frost, Stuckey, Smalley, & Dorman, 1982; Magee, 2008), photographic and software systems (Edmondston et al., 2012; Kuo et al., 2009) are commonly used and can be applied clinically.

To our knowledge there are a limited number of reviews around thoracic extension and rotation; the purpose of this literature review was to explore, critique and summarise the various clinical methods which are used to quantify thoracic extension and rotation. This would ultimately provide clinicians dealing with athletes such as surfers to select appropriate clinical methods to assess the thoracic region.

2.4.3. Methods

Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Liberati et al., 2009) for reporting systematic reviews of studies that evaluate healthcare interventions, a systematic review was conducted.

2.4.3.1. Database Search

A literature search was conducted using Pubmed, EMBASE, CINAHL, and SPORT-Discuss. The search was limited to articles involving human participants published in English language prior to March 2014. The search was conducted using search terms from four key subject areas: thoracic spine (“thoracic spine”, “thoracic vertebrae”, “thorax”, “thoracic”), range of motion (“range of motion”, “range”, “ROM”, “movement”, “joint range”), extension (“exten*”) and rotation (“rot*”). Each subject area used the Boolean operator “Or” to compile all material within each individual subject. Finally each subject search was combined with the Boolean operator “And”. A word from each of the four subject areas was required to be in the abstract or title.

Article titles and their abstracts were screened for relevance and the bibliographies of key articles were reviewed to identify any further relevant articles. Articles were deemed relevant for the literature review if they aimed to specifically measure thoracic extension or rotation with a method that could be used clinically. Essentially this meant that the method could be replicated in an outpatient clinic setting. Advanced software and biomechanical laboratory based studies were not considered clinically practical and were therefore not included in the literature search. Studies involving X-ray only and segmental assessment through passive accessory intervertebral movements were also not deemed appropriate.

Figure 8 illustrates the step by step process involved in the refinement of articles to be included in the literature review. It needs to be noted that the article selection process was conducted by the lead researcher. However two researchers were involved in the development of criteria used to select articles for the review.

2.4.3.2. Quality Assessment of Selected Articles

A thorough evaluation of study design was also implemented through the use of the critical appraisal tool (CAT); this evaluation process was conducted by one researcher and can be seen in Table 18. The CAT consists of 13 criteria which evaluates the psychometric properties of both reliability and or validity studies (Brink & Louw, 2012). This tool has previously been used in systematic reviews (Barrett, McCreesh, & Lewis, 2014) concerning clinical measures. As a quality score is not given when using the CAT, studies were considered of high quality if they scored $\geq 60\%$ (Barrett et al., 2014). The inclusion criteria for articles was not limited to articles with either a reliability or validity focus and therefore studies were included which performed a descriptive analysis of specific populations using a clinically relevant and novel technique. The CAT is designed to assess the psychometric properties of either reliability and or validity studies; therefore studies included in the literature search without the primary focus of reliability and or validity were not critiqued with the CAT. Meta-analysis was not conducted within this review due to the variations in tests, participants and analyses; a subgroup analysis was also not possible due to the limited number of studies using the same device, position and movements to test thoracic extension or rotation. However, a level of evidence approach modelled from Van Tulder, Furlan, Bombardier, and Bouter (2003) was used to provide a summary of the strength of evidence behind each device (see Table 21).

2.4.4. Results

The study selection process is summarised in a PRISMA flow diagram presented in Figure 8. A total of 15 studies were identified; two of the 15 studies assessed both thoracic extension and rotation taking the total to 17 studies which were evaluated. Of the 17 studies, six studies (Crawford & Jull, 1993; Kuo et al., 2009; Lenehan, Fryer, & McLaughlin, 2003; O'Gorman & Jull, 1987; Perriman et al., 2010) were not evaluated with the CAT as they did not have a reliability or validity focus. A total of 10 studies had a reliability focus and one study had a validity focus; nine studies of these were deemed high quality (see Table 18, Table 19 and Table 20). As previously stated a high quality study required at least 60% of the CAT criteria to be achieved (Barrett et

al., 2014). Of the 10 studies investigating reliability, three studies investigated inter-rater reliability, and seven studies investigated both inter and intra-rater reliability.

A level of evidence approach is presented in Table 21 which synthesises the data obtained in the reliability and validity aspects of the studies and whether or not the study was deemed high quality through the use of the CAT. This was completed for the type of device used; it needs to be noted that the position is also a major consideration however due to the heterogeneity between studies this was not possible.

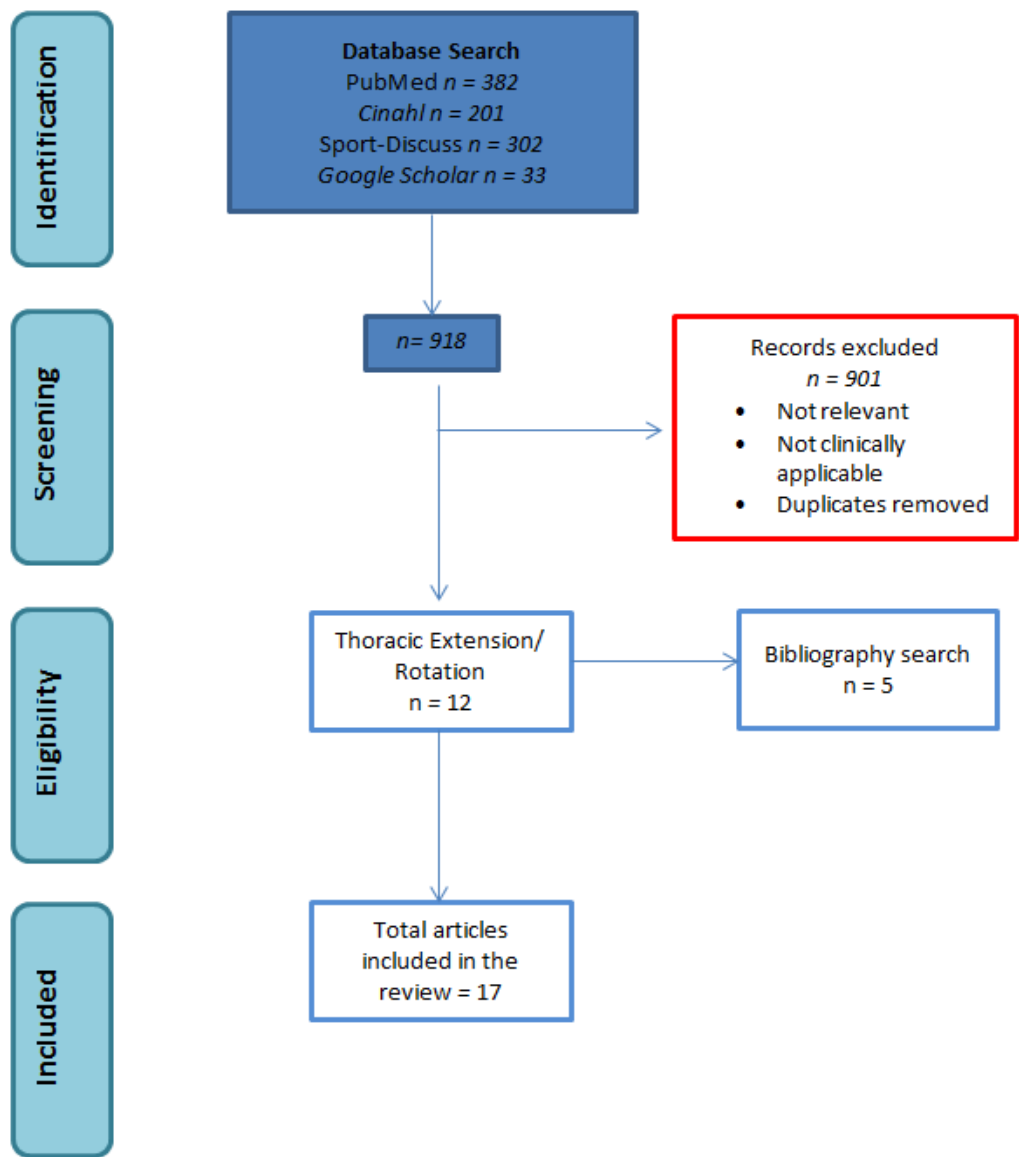


Figure 8: PRISMA Flow Diagram of Article Selection Process

Table 18: Quality Assessment of Articles using the Critical Appraisal Tool (CAT)

	Thoracic Extension													
Author	1	2	3	4	5	6	7	8	9	10	11	12	13	High Quality
Mellin, Kiiski, and Weckstrom (1991)	Yes	Yes	NA	NA	No	No	Yes	Yes	NA	Yes	NA	Yes	Yes	Yes
Troke et al. (1998)	Yes	Yes	NA	No	NA	No	Yes	Yes	NA	Yes	NA	no	Yes	Yes
Lee et al. (2003)	Yes	Yes	NA	Yes	No	No	No	Yes	NA	Yes	NA	No	Yes	Yes
Mannion, Knecht, Balaban, Dvorak, and Grob (2004)	Yes	No	NA	Yes	No	Yes	Yes	Yes	NA	Yes	NA	No	Yes	Yes
Kellis, Adamou, Tziliou, and Emmanouilidou (2008)	Yes	Yes	NA	Yes	Yes	Yes	Yes	Yes	NA	Yes	NA	No	Yes	Yes
Edmondston et al. (2012)	Yes	Yes	Yes	NA	NA	NA	NA	NA	Yes	Yes	Yes	No	Yes	Yes
O'Gorman and Jull (1987)	No validity or reliability focus													
Crawford and Jull (1993)	No validity or reliability focus													
Kuo et al. (2009)	No validity or reliability focus													
Perriman et al. (2010)	No validity or reliability focus													
	Thoracic Rotation													
Author	1	2	3	4	5	6	7	8	9	10	11	12	13	High Quality
Schenkman, Hughes, Bowden, and Studenski (1995)	Yes	No	NA	No	No	No	Yes	Yes	NA	Yes	NA	No	Yes	No
Schenkman, Laub, Kuchibhatla, Ray, and Shinberg (1997)	Yes	Yes	NA	No	No	No	No	No	NA	Yes	NA	No	Yes	No
Troke et al. (1998)	Yes	Yes	NA	No	NA	No	Yes	Yes	NA	Yes	NA	No	Yes	Yes
Iveson et al. (2010)	Yes	No	NA	Yes	No	Yes	Yes	Yes	NA	Yes	NA	No	Yes	Yes
Johnson et al. (2012)	Yes	Yes	NA	Yes	Yes	Yes	Yes	Yes	NA	Yes	NA	No	Yes	Yes
O'Gorman and Jull (1987)	No validity or reliability focus													
Lenahan et al. (2003)	No validity or reliability focus													

13 criteria include adequate description of subjects (1); adequate description of raters (2); adequate description of reference standard (3); between rater blinding (4); within rater blinding (5); variation of testing order (6); appropriate time period between index test and reference standard (7); appropriate time period between repeated measures (8); independency of reference standard from index test (9); adequate description of index test procedure (10); adequate description of reference standard (11); explanation of any withdrawals (12); appropriate statistical tests (13).

Table 19: Clinical Methods Aiming to Quantify Thoracic Extension

Author	Device/ Position	Subjects†	Key findings	ROM recorded (degrees)	High quality study*
(O’Gorman & Jull, 1987)	Inclinometers / Sitting	(20) females of 22-29 years	Thoracic extension significantly decreased with age.	$37.4^{\circ} \pm 10.52^{\circ}$	NA
(Mellin et al., 1991)	Inclinometers / Prone, standing and standing while leaning against a support.	(27) subjects of 24-58 years	High repeatability was seen for all extension movements ($r > .80$).	Prone: 13.4° , standing: 17.3° and standing with support: 17.0°	Yes
(Crawford & Jull, 1993)	Inclinometer/ Sitting	(30) Younger age group of 18-30 years	Kyphosis increased and thoracic extension decreased with age.	$29^{\circ} \pm 10^{\circ}$	NA
		(30) Older age group of 50-75 years.	As above.	$19^{\circ} \pm 9^{\circ}$	NA
(Troke et al., 1998)	OSI CA 6000 Spine Motion Analyser (SMA)/ Standing	(11) Subjects aged between 18-37 years.	Moderate inter-rater reliability (ICC .77) for flexion and extension.	$70^{\circ} \pm 16.23^{\circ}$ (only total ROM recorded)	Yes
(Lee et al., 2003)	Inclinometer/ Standing	(31) subjects aged 18-35 years.	Intra (ICC .48 -.79) and inter-rater (ICC .65 – .86) reliability was moderate to excellent.	20°	Yes
(Mannion et al., 2004)	A computer aided skin surface device (spinal mouse)/ Standing	(20) subjects aged $41 \pm$ 12 years.	Moderate to excellent intra (ICC .57-.95) and inter- rater reliability (ICC .62-.94) demonstrated.	$1.1^{\circ} \pm 13.0^{\circ}$	Yes
(Kellis et al., 2008)	A computer aided skin surface device (spinal mouse)/ Standing	(81) males aged $10.62 \pm$ 1.73 years.	Moderate to high intra (ICC .61 - .96) and inter rater (ICC .70 - .93) reliability demonstrated.	$1.61^{\circ} \pm 2.58^{\circ}$	Yes

Author	Device/ Position	Subjects†	Key findings	ROM recorded (degrees)	High quality study*
(Perriman et al., 2010)	Flexible electrogonio meter (FEG)/ Standing	(12) subjects, aged 43 ± 13 years.	High repeatability for all movements (ICC .94 - .98). The FEG angles recorded were highly correlated with X- Ray angles (ICC .77- .87).	8°	NA
(Edmondston et al., 2012)	Reflective markers and photographic analysis/ Standing	(21) subjects aged 18-28 years.	There was a significant correlation between photographic and radiographic measurements ($r =$.71, $p < .01$).	10.5° ± 4.4°	Yes
(Kuo et al., 2009)	Reflective markers/ Four point kneeling and in sitting	(24) subjects aged between 17-27 years.	The older age group achieved significantly less total thoracic flexion/ extension than the younger group.	48.5° ± 12.4° (only total ROM recorded)	NA
		(22) subjects aged between 60-83 years.	As above	33.6° ± 15.6° (only total ROM recorded)	NA

*High quality study assessment utilizes 13 criteria adapted from Brink and Louw (2012) critical appraisal tool (CAT); a study which achieved greater than 60% was regarded as high quality (Barrett et al., 2014).

†All subjects were considered “healthy”, with no known pathologies. No specific sporting subgroups or pathologies were included.

Table 20: Clinical Methods Aiming to Quantify Thoracic Rotation

Author	Device/ Position	Subjects†	Key findings	ROM recorded (degrees)	High quality study*
(O'Gorman & Jull, 1987)	A modified rotameter (large Perspex protractor mounted perpendicular to the base of the rotameter)/ Sitting	(20) Subjects aged 22-29.	No systematic differences could be demonstrated between trials.	60.28° ± 12.59° (R rotation) 59.30 ± 11.00 (L rotation)	NA
(Schenkman et al., 1995)	Functional axial rotation (FAR) device/ Sitting	(17) Subjects aged 20-74 years.	Intra (ICC 0.90 - 0.95) and inter-rater (ICC 0.97) reliability was excellent.	^140° ± 20° (R rotation) ^133° ± 22° (L rotation)	No
(Schenkman et al., 1997)	Functional axial rotation (FAR) device/ Sitting	(14) elderly aged 64-76 years.	Moderate to excellent ICC values for elderly: Intra (ICC 0.86), inter-rater (ICC 0.84);	69° (Total rotation)	No
		(14) Healthy young aged 23-31 years	healthy: Intra (ICC 0.86), inter-rater (ICC 0.65).	84° (Total rotation)	
(Troke et al., 1998)	OSI CA 6000 Spine Motion Analyser (SMA)/ Standing position	(11) Subjects aged 18-37 years.	Excellent inter-rater reliability (ICC .84).	64° ± 10.79° (Total rotation)	Yes
(Lenehan et al., 2003)	A custom made device known as the axial rotation measuring device (ARMD)/ Sittings	(59) Subjects aged 19-33 years	Reliability testing revealed a significant correlation between the two testing occasions ($r = 0.81$) for the same rater.	32.07° (Average for left and right rotation)	Yes
(Iveson et al., 2010)	Inclinometer/ Side-lying	(156) Subjects aged 17-24 years.	Intra and inter-rater reliability was excellent (ICC 0.87-0.94).	55.2° ± 9.7° (R rotation) 53.6° ± 10.7° (L rotation)	Yes

Author	Device/ Position	Subjects†	Key findings	ROM recorded (degrees)	High quality study*
(Johnson et al., 2012)	Goniometer/ Seated rotation (bar in back and bar in front), in a lunge position Inclinometer/ Four point kneeling position	(46) Subjects average age 23.6 ± 4.3, 18 – 45 years.	Intra (ICC .86 - .95) and inter-rater (ICC .85 - .94) reliability was excellent.	Seated rot; bar in back: 41.6°, bar in front: 55.4°; half kneeling rot; bar in back: 48.2°, bar in front 60.6°; four point kneeling: 40.8°.clinicians (all values are averages for left and right rotation)	Yes

*High quality study assessment utilizes 13 criteria adapted from Brink and Louw (2012) critical appraisal tool (CAT); a study which achieved greater than 60% was regarded as high quality (Barrett et al., 2014).

†All subjects were considered “healthy”, with no known pathologies. No specific sporting subgroups or pathologies were included.

^ This method allowed for additional rotation from above and below the thoracic spine.

Table 21: Level of Evidence Supporting the Devices used to Quantify Thoracic Extension and Rotation

	Method	Reliability	Validity	Level of evidence*
Thoracic Extension	Inclinometer	Moderate to high intra and inter rater reliability	NA	Moderate
	Spinal mouse	Moderate to high intra and inter rater reliability	NA	
	Spinal motion analyser (SMA)	Moderate inter rater reliability	NA	Limited
	Photographic analysis	NA	Moderate validity	
Thoracic Rotation	Inclinometer	Very high intra and inter rater reliability	NA	Moderate
	Goniometer	Very high intra and inter rater reliability	NA	Limited
	Spinal motion analyser (SMA)	High inter rater reliability	NA	
	Functional axial rotation method (FAR)	Very high intra and inter rater reliability	NA	

*Levels of evidence approach adapted from Van Tulder et al. (2003). Strong evidence refers to consistent findings from three or more high quality studies; moderate evidence refers to consistent findings from at least one high quality and one or more low quality studies; limited evidence refers to consistent findings in one or more low quality studies or only one study is available.

2.4.5. Discussion

This discussion presents a summary of the findings for thoracic extension and rotation independently of one another.

2.4.5.1. Quality of Selected Articles Thoracic Extension Methods

Of the 10 studies selected for the thoracic extension portion of the review, four of the studies did not have validity and or reliability focus; therefore only six studies could be critiqued using the CAT. All six studies were deemed high quality scoring at least 60%; however common flaws were consistently identified. Firstly intra-rater blinding was not provided in three (Lee et al., 2003; Mannion et al., 2004; Mellin et al., 1991) of the six studies; blinding is imperative as knowledge of previous findings may influence repeated measures and inflate the intra-rater agreement scores (Barrett et al., 2014; Brink & Louw, 2012). The order of examination was not varied in these same three studies; variation in test order can reduce systematic bias by reducing learning effects which occur with repeated movements (Lexell & Downham, 2005). Variation in test order can also reduce the examiners ability to recall previous test scores and therefore reduce bias (Brink & Louw, 2012). Only one (Mellin et al., 1991) out the six studies accounted for participant withdrawal; this criteria is relevant as changes in the sample composition will influence the reliability and or validity performance of the index tool (Brink & Louw, 2012).

From a positive perspective all six studies used appropriate statistics to analyse and present the data; provided appropriate explanations of the index test; provided adequate time between repeated measures to limit errors due to fatigue and gave an adequate description of the subjects being tested. Five of the six studies provided adequate description of the competence of the raters; this is useful as the ability to palpate land marks can greatly affect reliability and thus examiners need to be highly trained. As all six studies evaluated were deemed high quality their associated findings are considered with greater weighting and significance. It also needs to be mentioned that only one of the six studies had a validity focus; this may be attributed to the difficulty of using X-ray as a comparative gold standard to determine concurrent validity. The lack of validity focus raises concerns regarding the extent to which thoracic extension is actually being represented and provides insight into the inconsistencies in the ROM expressed in the reviewed articles (see Table 19).

2.4.5.2. Quality of Selected Articles for Thoracic Rotation Methods

Of the seven selected studies, five were deemed appropriate to be critiqued using the CAT (Table 18). Two (Schenkman et al., 1995; Schenkman et al., 1997) of the five articles were determined to be of low quality scoring less than 60% with key psychometric properties absent from the methods used in both of these studies. Interestingly both studies used the functional axial rotation method (FAR). Of the three studies (Iveson et al., 2010; Johnson et al., 2012; Troke et al., 1998) which were determined to be of high quality a consistent limitation was the inability to account for withdrawals. Strengths of the high quality studies were the adequate description of subjects and raters, inter and intra-rater blinding, appropriate explanation of index test, appropriate distance between measures and appropriate statistics used.

2.4.5.3. Positioning of Subjects for Thoracic Extension Methods

It is apparent that four primary positions are used to determine thoracic extension; sitting, standing, four point kneeling and in prone. The sitting position allows for the hips and lumbar spine to be stabilized, however the amount of distal stabilisation varied between studies. This was illustrated by Crawford and Jull (1993) where a back rest was positioned at the level of L1 to limit any lumbar movement (see Figure 9, D). Conversely Kuo et al. (2009) who utilized a four point kneeling position allowed the lumbar and cervical spines to be involved as the researchers believed this would enhance the physiological movement at the thoracic spine. Mellin et al. (1991) utilized a standing position and provided no distal stabilization of the lumbar spine or hips (see Figure 9, B and C). It could be argued that the standing position has more bias towards stressing the lumbar spine, especially as this position is generally accepted as the preferred clinical method to assess the lumbar spine (Magee, 2008). The standing position also provides difficulty to patients who have balance deficits as full extension may not be achieved due to the fear of falling backwards.

Mellin et al. (1991) was the only study identified that used a prone position to determine thoracic extension. Interestingly this study also reviewed the standing position and found no significant differences in the degree of thoracic extension between the two positions. It also reviewed thoracic flexion and found a significantly ($p \leq .05$) greater amount of flexion was achieved in a seated position versus a standing position. This may provide some evidence that the thoracic spine is more

stressed in the sitting position compared to standing as the weight of the head and shoulders assist with thoracic flexion.

It would seem more logical to utilise a position that allows associated spinal movements to occur if it could increase the thoracic ROM achieved; especially if adjacent spinal movements can be accounted for. It is also imperative that the movement itself stresses the thoracic region greater than the spinal regions above and below.

2.4.5.4. Positioning of Subjects for Thoracic Rotation Methods

Several positions were identified which assessed thoracic rotation using a replicable clinical method. Johnson et al. (2012) identified five differing positions; 1) sitting with a bar in front of the chest (see Figure 10, C); 2) an alternate position with the bar behind the back (see Figure 10, A); 3) a half kneeling position (see Figure 10, D and E) with one knee on the ground a bar in front of the chest; 4) an alternate position with the bar behind the back; 5) in a four point kneeling position (see Figure 11, A). All positions revealed excellent reliability values for within and between clinicians; however perceived advantages and disadvantages were associated with each method. The bar in front variations for both seated and in half kneeling allowed for easier visualisation of anatomical landmarks. The bar in the back position is thought to reduce the contribution from the shoulder joints on spine rotation. Both seated rotation tests may provide greater stability for those patients who have difficulty maintaining balance in the half kneeling position, however great difficulty exists when trying to maintain the goniometer at the T1/2 level while the subject rotates (see Figure 10, B).

The lumbar-locked position required patients to be in maximal hip and knee flexion which may pose some difficulty for patients with degenerative diseases such as knee or hip osteoarthritis. A key advantage to the lumbar-locked position is it only requires an inclinometer, both the seated and half kneeling positions require multiple pieces of equipment (bar, ball and goniometer).

The most commonly adopted position was in sitting, with five out of the seven studies using this position (Johnson et al., 2012; Lenehan et al., 2003; O'Gorman & Jull, 1987; Schenkman et al., 1995; Schenkman et al., 1997). A functional axial rotation (FAR) method was used in two studies (Schenkman et al., 1995; Schenkman et al.,

1997); here the subject sat on a backless chair with the pelvis stabilised with two straps. The subject was instructed to rotate their head and thorax as far as possible with both arms relaxed by their sides. Interestingly only one study was identified which used a standing position to determine thoracic rotation (Troke et al., 1998). An obvious limitation with this method is that it allows for considerable hip movement and therefore the specificity of thoracic rotation is questionable. Iveson et al. (2010) used a method known as the Side Lying Thoracolumbar Rotation Measurement (STRM); the subject's knees and hips were flexed to 90 degrees with the hand closest to the bed on the subjects ipsilateral knee and the other hand on the subjects ipsilateral hip in order to limit accessory hip or pelvic movement (Figure 12).

2.4.5.5. Devices Used for Thoracic Extension Methods

This review identified several devices which can be used to assess thoracic extension ranging from inclinometers (Crawford & Jull, 1993; Lee et al., 2003; Mellin et al., 1991; O'Gorman & Jull, 1987); reflective markers with photographs (Edmondston et al., 2012; Kuo et al., 2009); a skin surface device (spinal mouse) which is rolled along the curvature of the spine (Kellis et al., 2008; Mannion et al., 2004); a spine motion analyser (SMA) which is fixated to the skin (Troke et al., 1998) and a flexible electronic goniometer (Perriman et al., 2010).

The devices identified in the review vary in terms of cost and the amount of time for application. The inclinometer appears superior in terms of cost and time efficiency; interestingly no papers were identified which utilized a tape measure technique similar to what is used for lumbar flexion and extension (Alaranta, Hurri, Heliovaara, Soukka, & Harju, 1994; Beattie, Rothstein, & Lamb, 1987; Frost et al., 1982). Magee (2008) identified a method which uses a tape measure to assess thoracic extension and flexion in a standing position, unfortunately its reliability or validity has not been established. Frost et al. (1982) also used a tape measure technique, which encompassed both the thoracic and lumbar spine, therefore this method was not specific to the thoracic spine. A level of evidence approach is seen in Table 21; identifying the inclinometer and spinal mouse having a moderate level of evidence and the SMA and photographic analysis having a limited level of evidence.

2.4.5.6. Devices Used for Thoracic Rotation Methods

A functional axial rotation (FAR) method was used in two of the studies identified in this review; this method uses a hoop placed on adjustable poles at eye level of the subject with letters spaced every five degrees along the inside of the hoop. The subject wearing a Cervical ROM device (CROM) with a pointer on the top is placed on a backless chair in the middle of the hoop. Schenkman et al. (1995) initially assessed functional axial rotation (FAR) by looking at the physical motion (FARp) available and the ability to visually identify objects (FARv). The ROM recorded on the CROM was not subtracted from the total axial rotation. When performing the movement subjects were not restricted with respect to motion of the torso (e.g. extension, lateral flexion and flexion). Although this movement quantifies axial rotation at the trunk other movements were not limited and therefore thoracic rotation was not isolated. Schenkman et al. (1997) used a modified FAR method with the ROM recorded on the CROM subtracted from the total axial rotation. Other trunk movements including extension, side-flexion and flexion were not prohibited during axial rotation. This modified version of the FAR method is more specific for quantifying thoracic rotation and hence the reduction in thoracic ROM expressed (see Table 20). It needs to be noted that both of these studies were considered low quality and results should be viewed with caution (Table 18 and Table 20).

Inclinometers were utilized in two of the studies (Iveson et al., 2010; Johnson et al., 2012); with one study using the Lumber Locked Method and another using the STRM. Inclinometers revealed moderate levels of evidence in comparison to goniometry, SMA and FAR methods which were identified as limited levels of evidence (see Table 21). Interestingly goniometers were only used in one study (Johnson et al., 2012). Lenehan et al. (2003) used a customized device known axial rotation measuring device (ARMD). The device uses a protractor as the base and is positioned on the floor with a connecting bar positioned at the interscapular line of the patient. O'Gorman and Jull (1987) used a device where a modified rotameter (large perspex protractor mounted perpendicular to the base of the rotameter) was placed on L1 and a wire pointer was placed on T1. Further detail on the methodology for the devices used in each study is seen in Table 20.

2.4.5.7. Starting Position for Thoracic Extension Methods

The instructions and the actual movements used to determine thoracic extension varied between studies. Crawford and Jull (1993); O'Gorman and Jull (1987) initially determined thoracic kyphosis in a standing position (Figure 9, A) then got the subject to extend in a seated position (Figure 9, D) Therefore the thoracic kyphosis value was determined as the starting position and the thoracic extension was the ROM achieved in full extension minus the thoracic kyphosis value. This method was also used for the study by Lee et al. (2003) where kyphosis was determined in standing and the subject then extended; the change in angle determined the amount of thoracic extension (Figure 9, A and B). Kuo et al. (2009) used a slightly different technique in four point kneeling; the starting position was determined by what the subject felt was their neutral position and then the subject fully extended or flexed. Photographs obtained with reflective markers enabled the range of thoracic extension to be calculated. Troke et al. (1998) used a technique where a SMA was fixated onto the skin and the subject was positioned in standing and was asked to maintain a neutral starting position; the subject then maximally flexed and extended.

As the starting position to assess thoracic extension can vary which ultimately affects the extension or flexion expressed, total ROM was often reported (Crawford & Jull, 1993; Kellis et al., 2008; O'Gorman & Jull, 1987; Troke et al., 1998). It seems this value would be more indicative of thoracic mobility in the sagittal plane. This may be relevant for methods where the starting position is based off neutral thoracic kyphosis; here if a subject had a minimal kyphosis angle the amount of thoracic extension may be under-represented as opposed to reviewing the total ROM.

2.4.5.8. ROM Achieved During Thoracic Extension Methods

The amount of thoracic extension, total ROM and total thoracolumbar ROM varied dramatically between studies (see Table 19) revealing large inconsistencies. This may be primarily due to the testing position, device used and the lack of validity studies. Electronic devices such as the spinal mouse (Kellis et al., 2008; Mannion et al., 2004) or reflective markers (Edmondston et al., 2012) provided much smaller values of thoracic extension and total thoracic ROM compared to the use of inclinometers (Crawford & Jull, 1993; O'Gorman & Jull, 1987). Interestingly both studies (Crawford & Jull, 1993; O'Gorman & Jull, 1987) which involved inclinometers used a sitting position to determine thoracic extension. In this position the thoracic

spine is more easily extended and flexed compared to a standing position which tends to provide more bias towards the lumbar spine.

The amount of extension was almost negligible in some studies (Kellis et al., 2008; Mannion et al., 2004) making comparisons between studies very difficult. The lack of consistency between studies with regards to extension ROM raises concerns regarding the current methods available, especially considering the almost negligible extension values achieved in two high quality studies (Kellis et al., 2008; Mannion et al., 2004).

2.4.5.9. ROM Achieved During Thoracic Rotation Methods

The thoracic spine provides almost half of the entire trunk rotation (Kiesel, Burton, & Cook, 2004); this is primarily due to the coronal orientation of the thoracic facet joints which favours axial rotation (Edmondston et al., 2007). However it must be recognised that rotation of the trunk can also occur at the spinal regions above and below the thoracic spine and at the pelvis and hips. The amount of stabilization, involvement of accessory movements and position can all alter the total axial rotation recorded. Schenkman et al. (1997) found that in a sitting position using the modified FAR method total thoracic rotation was 84° in healthy adults. Using the same method however accessory movements were permitted and cervical motion was not subtracted from the total axial rotation Schenkman et al. (1995) revealed much higher values of rotation (92° to 190°).

Only two studies attempted to remove the lumbar spine ROM from contributing to the amount of thoracic ROM recorded. Johnson et al. (2012) used a Lumbar Locked Method (Figure 11) which puts the lumbar spine in flexion in an attempt to take up tension in the lumbar spinal ligaments; this limits the ability for the lumbar spine to contribute to any axial rotation. The total thoracic ROM recorded was lower than other methods where the lumbar spine was not stabilized (Johnson et al., 2012; Schenkman et al., 1995; Schenkman et al., 1997). Troke et al. (1998) used an indirect method to remove all lumbar contribution where by a spine motion analyser (SMA) device was placed on the spine from T1 to T12 and the subject maximally rotated their spine in standing; both the lumbar and cervical spines were permitted to rotate in the axial plane. Only the spinal motion occurring at the thoracic spine was recorded, with lower values of total thoracic ROM (64°) recorded compared to all other research. In comparison to thoracic extension there appears to be greater

consistency concerning the ROM achieved with thoracic rotation between studies as seen in Table 20.



Figure 9: Replication of the Position and Method of Measurement for Thoracic Extension

A) Thoracic kyphosis determined in standing with inclinometers placed on T1/2 and T1/L1 (adapted from Crawford & Jull, 1993); B) Thoracic extension in standing (adapted from Lee et al., 2003); C) Thoracic flexion in standing adapted from Lee et al., 2003); D) Thoracic extension in sitting (adapted from Crawford and Jull, 1993)

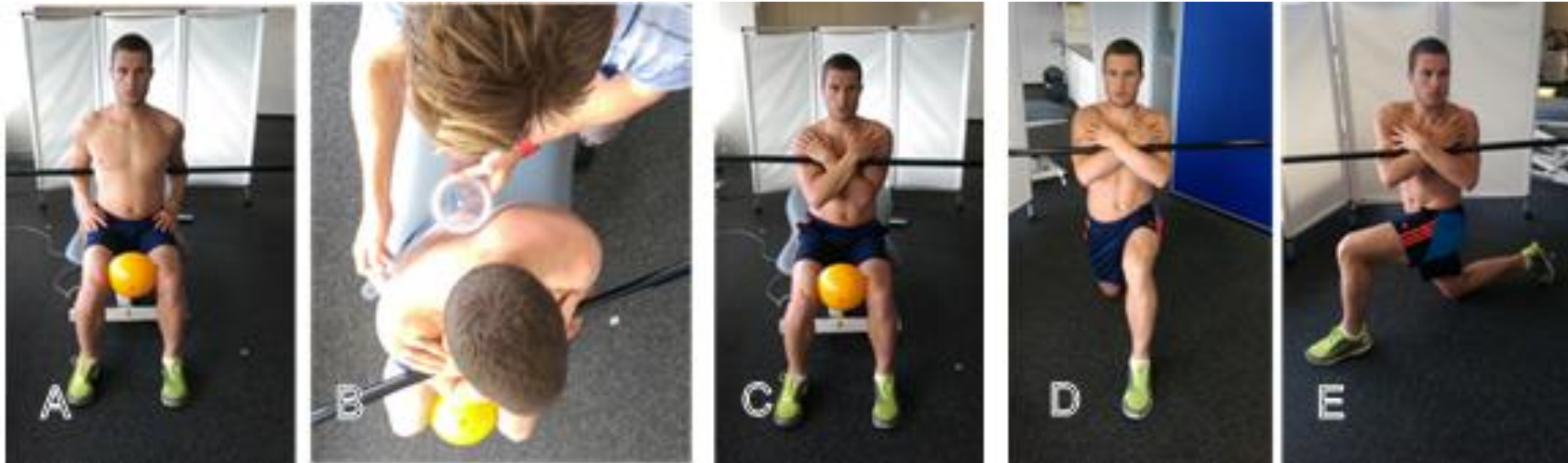


Figure 10: Replication of the Position and Method of Measurement for Thoracic Rotation (adapted from Johnson et al., 2012)

A) Thoracic rotation in sitting with bar behind back; B) Goniometer placement at T1/2 for all rotation movements above; C) Thoracic rotation in sitting with bar in front; D) Starting position for rotation



Figure 11: Replication of the Position and Method of Measurement for Thoracic Rotation (adapted from Johnson et al., 2012)

A) Lumbar Locked starting position; B) Right thoracic rotation with inclinometer placed at T1/2



Figure 12: Replication of Position and Method of Measurement for Thoracic Rotation (adapted from Iveson et al., 2010)

A) Sidelying Thoracic Rotation Measurement (STRM) starting position; B) Left STRM rotation end position

2.4.6. Conclusion

This literature review has identified a range of clinical methods for quantifying thoracic extension and rotation. Variation is seen throughout the identified studies with the position, device, instructions and ROM recorded all differing.

Regarding thoracic extension; a sitting or four point kneeling position may provide greater stress on the thoracic spine. Lumbar spine movement should be permitted as movement interaction between the spinal regions may permit a greater range of thoracic ROM. However, where possible the lumbar movement should be subtracted from the total ROM in order to truly quantify thoracic mobility in the sagittal plane. It should also be considered that the range of thoracic extension could be influenced by the magnitude of the neutral kyphosis, therefore the assessment of total ROM might be a better reflection of thoracic mobility in the sagittal plane. This accommodates for varying starting positions and varying kyphosis angles. An alternative starting position such as full flexion may also negate some of these issues.

The review highlighted that inclinometers appear to have moderate levels of evidence and are time efficient and cost effective. However unlike the lumbar region, there is limited use of simple tape measure techniques which aim to measure movement change in the thoracic spine. Future studies should look to address the reliability of such clinical methods.

Unlike thoracic extension methods, there is greater consistency concerning the ROM achieved with thoracic rotation between studies. Inclinometers appear to have the highest level of evidence (moderate) and both the Lumbar Locked method and STRM are the simplest methods to administer. Both of these methods are reliable, requiring only an inclinometer and attempts are made to fixate the lumbar spine, pelvis and hips. This is considered important with regards to thoracic rotation as ROM can vary if the lumbar spine, pelvis and hips are permitted to rotate.

2.5 CLINICAL METHODS TO ASSESS SHOULDER RANGE OF MOTION IN SUPINE AND PRONE: A REVIEW OF THE CURRENT LITERATURE

2.5.1. Preface

A literature review was performed to investigate clinical assessment techniques for measuring shoulder ROM (see Appendix 4). This review was performed by a Doctor of Physiotherapy student and the current candidate of this thesis was the supervisor. A summarised version of this review has been presented below which essentially provides the rationale for the prone assessment technique outlined in the following paper (section 2.6.2). The evidence of literature searching is also presented.

2.5.2. Introduction

Assessment of joint range of motion (ROM) is critical in determining baseline levels, diagnosis of disorders, evaluation of treatment and quantifying the degree of change. It is therefore crucial for information to be available on the reliability of ROM assessment techniques. To be relevant to clinical practice, this reliability must be high with the same clinician performing assessment (intra-tester) as well as between clinicians when patient care is transferred (inter-tester). If an athlete is being screened it is essential that the assessment techniques chosen are specific to sport the athlete participates in. By having knowledge of the key injury prone or regions under stress in a particular sport it may assist in choosing the appropriate assessment techniques.

Until recently, there has been very little data encompassing the stage, type and mechanism of injuries commonly occurring in surfers. A recent retrospective analysis study by (Furness et al., 2014; Furness et al., 2015) interviewed 1,348 recreational and competitive surfers. From these injuries, the shoulder had the largest distribution of acute injuries of any region (Furness et al., 2015). The repetitive nature of paddling in surfing may predispose participants to more acute and chronic injuries caused by muscle imbalance and associated shortening in the shoulder region (Mendez-Villanueva 2005). Currently no normative or comparative data exists relating shoulder muscle length in surfers to a normal population group. Prior to assessing shoulder ROM in a surfing population a specific and reliable technique must be chosen. Therefore the literature must be addressed and evaluated.

This review aims to explore simple clinical methods available to assess shoulder ROM (flexion, internal rotation (IR), external rotation(ER)). More specifically, to determine if prone assessment techniques are available and most importantly reliable. This position would be more specific to a surfing population.

2.5.3. Methods

A search was conducted by one independent reviewer to identify published articles looking at the reliability of shoulder range of motion testing in various anatomical positions. The search was limited to articles involving human participants published in English language prior November 2013. Search terms included: Shoulder, range of motion and all synonyms for reliability. Studies applied to this literature review were

identified by searching the following electronic databases: MEDLINE (Pubmed), Embase, CINAHL. In addition, reference lists of all papers retrieved were hand searched for relevant studies.

The titles and abstracts were screened by one reviewer. Articles were deemed relevant for the literature review if they aimed to specifically assess reliability of active or passive flexion, ER and IR using methods feasible for clinical practice. No restrictions were imposed on language or date of publication. When relevant, full text papers were retrieved. Studies using cadaver or animals were not considered for inclusion. Following screening, 7 published articles fulfilled all inclusion criteria (see figure 13).

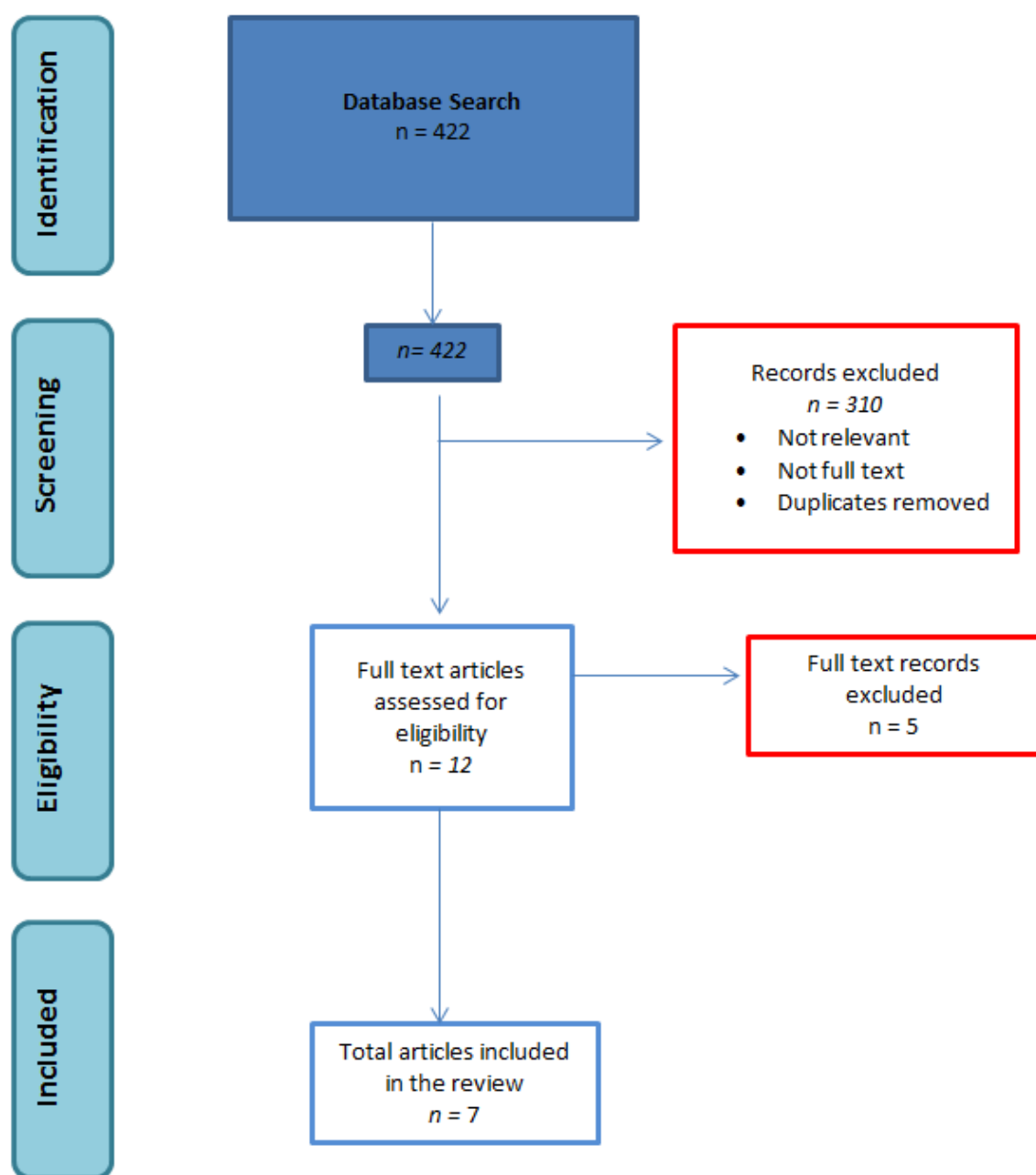


Figure 13: PRISMA Flow Diagram of Article Selection Process

Table 22: Comparison of Anatomical Position, Movement, Device and Reliability

Author	Position	Movement	Clinical device	Reliability*
Riddle et al. 1987	Supine	Flexion	Goniometer	Intra-rater, PROM, ICC = .98 Inter-rater, PROM, ICC = .89
Hayes et al. 2001	Sitting	Flexion	Goniometer	Intra-rater, AROM, ICC = .69 Inter-rater, AROM, ICC = .53
		ER	Goniometer	Intra-rater, AROM, ICC = .65 Inter-rater, AROM, ICC = .64
Muir et al. 2010	Supine	Flexion	Goniometer	Intra-rater, AROM, ICC = .92, PROM = .85 Inter-rater, AROM, ICC = .76, PROM = .78
	Supine	ER	Goniometer	Zero degrees abduction Intra-rater, AROM, ICC = .89, PROM = .94 Inter-rater, AROM, ICC = .89, PROM = .86 90 degrees abduction Intra-rater AROM, ICC = .93, PROM = .89 Inter-rater AROM, ICC = .95, PROM = .89
	Supine	IR	Goniometer	Intra-rater, AROM ICC = .87 Inter-rater, AROM ICC = .62
Wilke et al. 2009	Supine	IR	Goniometer	No stabilization Intra-rater, PROM, ICC = .48 Inter-rater PROM, ICC = .47 Scapular Stabilization Intra-rater, PROM, ICC = .62 Inter-rater, PROM, ICC = .43 Humeral Head Stabilization Intra-rater, PROM, ICC = .51 Inter-rater, PROM, ICC = .45
Kolber et al. 2009	Supine	ER	Inclinometer	Intra-rater, AROM, ICC = .97
	Prone	IR	Inclinometer	Intra-rater, AROM, ICC = .99
Lunden et al. 2010	Side lying	IR	Goniometer	Intra-rater, PROM, ICC = .94 – .98 Inter-rater, PROM, ICC = .88 – .96
Kolber et al. 2012	Seated	Flexion	Digital Inclinometer and Goniometer	Intra-rater, AROM, ICC = .95
	Supine	ER	Digital Inclinometer and Goniometer	Intra-rater, AROM, ICC = .94 – .98
	Prone	IR	Digital Inclinometer and Goniometer	Intra-rater, AROM, ICC = .95 – .97

*ICC refers to Intra class correlation coefficient; AROM refers to active range of motion; PROM refers to passive range of motion; IR refers to internal rotation and ER refers to external rotation

2.5.4. Discussion

This literature review included seven studies which meet the inclusion criteria investigating reliability of joint ROM testing of the shoulder. The purpose of this review was to explore the reliability of clinical methods of shoulder ROM assessment (flexion, ER and IR) and more specifically to determine if reliable assessment methods are available in the prone position. Excellent to moderate ICC scores were identified between studies (see Table 22). Differing, positions, devices and methodologies may provide rationale for variations in reliability scores. Muir, Corea, and Beaupre (2010) hypothesized reasons as to why variation in reliability values can arise. This includes the land marking during goniometer placement and the lack of stabilization of the shoulder girdle to prevent compensatory scapula-thoracic movements during rotation.

With regards to anatomical position of the seven studies five of the studies performed shoulder joint ROM testing in supine compared to the other positions (sitting, side lying and prone). This was the case for all shoulder movements (flexion, ER and IR) reviewed. Surprisingly only two studies (Kolber & Hanney, 2012; Kolber, Saltzman, Beekhuizen, & Cheng, 2009) were identified which utilized a prone position. Both studies revealed excellent reliability scores ($ICC > .75$) for prone IR. Interestingly neither study assessed ER in the prone position. To our knowledge no study exists which assesses shoulder ER in a prone position. Applying the principle of specificity for a prone dominant athlete should result in shoulder assessment in this position.

When comparing active to passive ROM, lower ICC scores were found in passive range measurements (see Table 22). However only one study (Muir et al., 2010) identified, directly compared active and passive movements. The variation in passive ROM measurements may be due to the difficulties with clinicians applying a reliable amount of force when attempting to attain full range of motion. This is an important consideration for clinical use especially when multiple clinicians are assessing or treating the same patient. Active movement testing may therefore be preferable to passive testing in order to evaluate change in a patient's condition (Muir et al., 2010).

Reliability differed between studies even when the same movement and position was applied. This was evident with respect to shoulder IR in supine with a variation in ICC scores (.43-.87) (Muir et al., 2010; Wilk et al., 2009). Differences in ICC scores may be attributed to variations in methodology. Wilk et al. (2009) compared three methods

of measuring IR and found the highest reliability to be with scapular stabilization method (ICC = .62). Significant differences in ROM were shown with the three methods of measuring IR (no stabilization, scapula stabilization, humeral head stabilization). This displays the effect variations in methodology has on evaluating shoulder ROM.

2.5.4.1. Key findings

- A reliability study which assesses shoulder ER in prone is yet to be conducted.
- Active ROM assessment appears to be more reliable than passive assessment.
- Discrepancies in reliability scores are evident despite studies adopting the same testing position and performing the same movement. This highlights the effect of variation in methodology.
- Goniometer and inclinometers appear to be the most clinically used assessment tools.

2.5.5. Conclusion

This review has established that only two studies exist that utilize a prone position to assess shoulder IR. To our knowledge no studies exist that assess the reliability of ER in a prone position. Additionally no comparison has been made between prone and supine shoulder assessment, which would inform a clinician as to whether or not either position can be used interchangeably. Future research should be directed at evaluating the reliability of shoulder ROM assessment in the prone position. From a sport specific screening perspective, the prone position may be more specific for many popular sports including swimming and surfing.

2.6. STUDY 2: RELIABILITY STUDY

Following on from section 2.4 it was identified that there was a lack of consistency between studies which reviewed thoracic extension methods. There was also limited use of simple tape measure techniques which aim to measure movement change in the thoracic spine.

Section 2.5 also reviewed the literature specific to prone shoulder assessment and identified the absence of clinical methods to evaluate shoulder ROM in a prone position. Study 2 was therefore implemented to determine the reliability of two ROM methods for thoracic mobility in the sagittal plane and shoulder ER and IR in a prone position.

This study received ethics approval from the Bond University Ethics Committee (see Appendix 1). The results of Study 2 are presented in two papers in section 2.6.1 and 2.6.2.

2.6.1 TRUNK MOBILITY IN THE SAGITTAL AND HORIZONTAL PLANES: **CLINICAL METHODS TO QUANTIFY MOVEMENT IN AN ELITE MALE** **SURFING POPULATION**

The results of Study 2 for determining the reliability of thoracic ROM assessment methods are presented in the following paper. This is an Accepted Manuscript of an article published online by Elsevier in 2015 in the journal of *Physical Therapy in Sport*, available online: DOI: 10.1016/j.ptsp.2015.09.003. Reprinted with permission.

Furness, J., Hing, W., Abbott, A., Sheppard, J. M., & Climstein, M. Trunk mobility in the sagittal planes: clinical methods to quantify movement in an elite surfing population, *Physical Therapy in Sport* (2015), doi: 10.1016/j.ptsp.2015.09.003.

2.6.1.1. Abstract

Background: High numbers of acute shoulder and chronic lumbar injuries have been identified in a surfing population. A simple screening tool could be used to determine whether thoracic spine dysfunction is a possible contributor to shoulder or lumbar injuries. Importantly, thoracic mobility in the sagittal and horizontal planes are key requirements in the sport of surfing; however to date the normal values of these movements have not yet been quantified in a surfing population.

Objectives: To develop a reliable method to quantify thoracic mobility in the sagittal plane; to assess the reliability of a thoracic rotation method, and quantify thoracic mobility in an elite male surfing population.

Design: Clinical Measurement, reliability (repeated measures) and comparative study.

Methods: 27 subjects were used to determine the reliability of a new method to assess thoracic mobility in the sagittal plane and 30 subjects were used to confirm the reliability of an existing thoracic rotation method. A total of 15 elite surfers were used as part of a comparative analysis with age and gender matched controls.

Results: Intra-rater reliability (within and between session) intraclass correlation coefficient (ICC) values ranged between .95-.99 for both thoracic methods in the sagittal plane and between .95-.98 for the rotation method. There was no significant difference in the amount of thoracic mobility in the sagittal plane between groups; however the elite surfing group had significantly ($p \leq .05$) greater rotation than the comparative group (mean rotation 63.6 vs.. 40.8 degrees respectively). Symmetry was also confirmed between left and right thoracic rotation in the elite surfing group (63.1 vs.. 64.0 degrees).

Conclusion: This study has illustrated reliable methods to assess the thoracic spine in the sagittal and horizontal planes. It has also quantified ROM in a surfing cohort; identifying thoracic rotation as a key movement. This information may provide clinicians, coaches and athletic trainers with imperative information regarding the importance of maintaining adequate thoracic rotation and symmetry. From a screening perspective thoracic rotation should be assessed for performance purposes and to limit the potential for injury in the thoracic spine or in surrounding regions.

2.6.1.2. Introduction

It appears that the thoracic spine is a region which has been neglected when it comes to the consensus on gold standard clinical methods to measure range of motion (ROM) (Edmondston et al., 2012; Johnson & Grindstaff, 2010). One of the difficulties of isolating the thoracic region is that multiple joints above and below contribute to thoracic spine ROM (Kuo et al., 2009). The thoracic movements of interest have generally been in the sagittal and horizontal planes; especially when considering the coronal orientation of the thoracic facets joints favour rotation.

Physiotherapists usually attempt to utilize musculoskeletal screening measures that are specific to the sport the athlete participates in; however methods used must be standardised and shown to be reliable and valid (Spurrier, 2015). Generally the premise behind musculoskeletal screening is three fold. This involves identifying limitation or asymmetry, enhancing performance and identifying injury prone regions (Spurrier, 2015). It would be deemed appropriate that athletes whose sports have a significant amount of stress on the thoracic spine would require a clinical method to assess this region.

In the case of surfing the thoracic spine is a key region which is stressed; especially considering that the consequences of reduced range of motion may result in stress on surrounding joints and potentially affect performance (Furness et al., 2014). The sport of surfing can be broken down into three key phases; paddling (45% of the time), sitting (50% of the time) and actual wave riding (5% of the time) (Farley, Harris, & Kilding, 2012b; Meir et al., 1991). During paddling the thoracic spine must be held in a prolonged extended position to allow for adequate arm clearance (Everline, 2007). A reduction in thoracic extension during paddling could potentially result in greater pressure via extension occurring at the lumbar spine or cervical spine (Furness et al., 2014). It could also result in greater shoulder abduction and extension to clear the water, thus causing shoulder impingement.

During actual wave riding, thoracic rotation is a critical movement to assist in producing torque during turning manoeuvres; this is illustrated in Figure 14. The surfer rotates towards the wave during the bottom turn and away from the wave during the top turn. During these movements the thoracic spine also flexes during the bottom turn and extends during the top turn; a combination of ROM and strength is needed with this movement. It could be suggested that for high-performing surfers, limitations in thoracic extension and rotation would result in the athlete “turning out of

their lower back”, something that is generally identified as poor-scoring technique, and injurious.

When designing a surf specific musculoskeletal screen it is imperative to look at key injury prone regions and specific joints which are under stress during the activity. Furness et al. (2014) revealed the two key areas with the highest frequency of chronic injury were the shoulder and lumbar spine. With regards to acute injuries the shoulder has been shown to have the highest frequency of injuries (Furness et al., 2015). The thoracic spine serves as a link between these two locations and could be a contributing factor to injuries sustained in both the lumbar spine and shoulder. Poor thoracic mobility has been associated with increased cervical pain and lumbar pain (O'Gorman & Jull, 1987) and shoulder pathology (Lewis & Valentine, 2010). Treatment directed at the thoracic spine has been associated with improvements in a range of musculoskeletal conditions including cervical and shoulder pathologies (Iveson et al., 2010). An inability to attribute these findings to improvements in thoracic ROM may be due to the lack of feasible and reliable clinical methods to quantify thoracic ROM (Iveson et al., 2010).

It could be proposed that the poor thoracic mobility or excessive kyphosis during paddling could cause the scapular to be protracted and downwardly rotated leading to potential compression of the subacromial tissues (subacromial bursa and rotator cuff tendons). This could also result in compensatory cervical extension or lumbar extension while paddling. It could be speculated that reduced thoracic rotation could result in greater stresses placed on the lumbar spine and hips. Simple screening measures to assess the thoracic spine could potentially rule in or out this region as a possible contributor.

A thorough systematic literature review (see section 2.4.) was conducted to identify clinical tests which could be used in assessing thoracic extension and rotation. When reviewing literature around thoracic extension large variations existed in the ROM expressed, the actual test position, clinical devices used and the starting position. Due to the large discrepancies it was deemed appropriate to design a new sports specific method to determine thoracic mobility in the sagittal plane. The literature around thoracic rotation revealed less variation with ROM expressed, starting positions and devices used. The lumbar locked position was determined an appropriate method to quantify thoracic rotation as it is easily applied clinically and requires minimal equipment. Therefore the purpose of this study was to establish a reliable method to quantify thoracic movement in the sagittal plane; to assess the

reliability of the lumbar locked method (thoracic rotation) and quantify thoracic mobility in an elite surfing population.



Figure 14: An Example of Thoracic Rotation During a Top Turn Manoeuvre, Adapted from ASP (2014)

2.6.1.3. Methods

2.6.1.3.1. Subjects

Reliability testing was completed on 27 individuals for the thoracic methods in the sagittal plane and 30 subjects for the rotation method; a sample size of 15-20 is often used in reliability studies with continuous data (Lexell & Downham, 2005). Participants were asked to complete a subjective questionnaire reporting age and injury history. This was done to gather background and demographical information about participants. The study was approved by the Bond University Ethics committee (RO1610) and informed consent was gained from all participants. Subjects were eligible for the study if they were between the ages of 18 – 75 years and able to adopt the starting position (four point kneeling with hips and knees in maximal flexion).

Exclusion criteria included any acute or chronic spinal pathology (in the past 3 months) that may be aggravated or worsened through repeated testing of thoracic extension, flexion and rotation. Based on these aforementioned criteria, no participants were excluded. Participants were between the ages of 20 and 57 years with the mean age being 30.83 (SD = 10.96) years. A total of 27 subjects (12 males and 15 females) were utilised to determine the reliability of the thoracic methods in the sagittal plane with the average age being 31.69 ± 11.52 years (range 20 to 57). A total of 30 subjects (16 females and 14 males) with a mean age of 30.84 (SD = 10.96) years (range 20 to 57) were used for determining reliability of the thoracic rotation method.

Comparative analysis was completed on 15 elite surfers, all of which were males with a mean age of 26.47 ± 4.59 years (range 18 to 34 years). Five of the male surfers were competing on the World Championship tour (WCT) which involves the top 32 ranked surfers in the world. The remaining surfers were competing on the World Qualifying Series (WQS) ranked in the top 100 surfers in the world.

2.6.1.3.2. Raters

The evaluators were two Physiotherapists, one with seven years of clinical experience in the assessment and treatment of orthopaedic conditions and the other a new graduate Physiotherapist. The new graduate performed all measurements and the other physiotherapist recorded; this was done to ensure blinding occurred throughout

all measurements. Data collection began in January 2014 and concluded in February 2014.

2.6.1.3.3. Equipment

Several devices were used within this study. A standard gravity dependent inclinometer (Universal Inclinometer, model UI01, Performance Attainment Associates, Minnesota, United States) was used for range of motion measurements. For thoracic rotation a horizontal reference point was used to ensure an accurate zero starting point, this was also established through the use of a bubble level.

The HALO (model HG1, HALO Medical Devices, Australia) is a new device on the market and is promoted as a digital way of recording joint range of motion. This device works through the use of magnets and accelerometers and is said to provide measures in the sagittal, coronal and transverse planes. The same HALO device was used for all joint range of motion measures in this study. To our knowledge, there is currently no available research investigating the reliability and validity of this device in measuring range of motion.

A standard medical tape measure was used with a centimetre scale on one side and an inch scale on the other; this was used for the assessment of thoracic mobility in the sagittal plane only.

2.6.1.3.4. Design

The two evaluators participated in a one hour formal training session prior to data collection. The training session was undertaken by a physiotherapist with post graduate qualifications in musculoskeletal physiotherapy. Participants were provided with verbal instruction and performed the required movement three times as a warm up under the guidance of the assessors; this was done in order to minimise the risk of a learning effect. This procedure was standardised for all testing and we believe offered no mobilisation effect. Prior to all testing both T1, T1/2 and T12 were marked on each subject. As previously used by Lewis and Valentine (2010) T1 was identified by asking the subject to maximally flex their cervical spine; the most protruding spinous process was identified as C7 and T1 was directly inferior to this. If C6 and C7 was difficult to distinguish the subject was asked to flex and extend their cervical spine while continuing to palpate C7; if the spinous process was not felt to disappear in

extension C7 was confirmed. In order to identify T12 the superior aspect of the subject's iliac crest was palpated and both thumbs were directed medially to meet at the spine. The intervertebral level palpated was determined as L4/5; this method was adapted from previous research (Kellis et al., 2008). Once the L4/5 level was determined the evaluator counted superiorly to T12 and this level was marked.

2.6.1.3.4.1. Thoracic Mobility in the Sagittal Plane

The participant was positioned in sitting on an adjustable medical bed with their knees flexed at 90 degrees and both feet positioned on the floor. Hands were clasped together and were placed on the back of the neck to minimize cervical movement; both elbows remained horizontal and facing forwards. The participant then flexed the entire spine dropping both elbows directly downward. The verbal instruction given involved asking the participant to, "Bend their entire spine by dropping their elbows in a downward direction as far as possible". As hip movement could potentially increase the amount of flexion both elbows were closely monitored to ensure they did not move in a forwards direction. Once a maximally flexed position was attained, this was considered the starting position and a tape measure was placed from T1 to T12 to record the starting position.

The participant then extended their entire spine by pointing both arms upwards as far as possible with the tape measure placed on the same landmarks and the distance recorded (A and B in Figure 15). The verbal instruction given involved asking the participant to, "Extend their entire spine by pointing their elbows in an upward direction as far as possible". The final measure was subtracted from the initial measure and represented the total range of thoracic mobility in the sagittal plane. The criteria for "failure" of the required movements involved the participant being unable to maintain a maximally flexed or extended position to allow for measurement or additional movement in the coronal or horizontal planes. If this occurred the participant was corrected and the movement was repeated.

The same procedure was utilized with a HALO device, which was placed at T1/2 and 'zeroed' at the starting position (C in Figure 15). The participant then maximally extended their spine by pointing their elbows upwards with the amount of thoracic mobility recorded on the inclinometer or HALO (D in Figure 15). T1/2 was chosen as the landmark for this assessment method as it has previously been used for measuring thoracic mobility in the sagittal plane (Lee et al., 2003; O'Gorman & Jull,

1987). It needs to be noted that the HALO method does not distinguish between lumbar or thoracic movement and is considered to assess thoracolumbar mobility in the sagittal plane. A second HALO device could have been placed on T12/L1 and movement here subtracted from the total range, however this was considered time consuming for the clinician and a global method was chosen as an alternative technique.

The tape measure method was adapted from the distraction method used in the lumbar spine (Tousignant et al., 2005) where a line is drawn connecting both posterior iliac spines and a mark on the lumbar spine 15cm superior to this. The subject in standing then extends backwards with the distance between the two markers recorded. It was deemed appropriate to use a sitting position as this has been shown to bias the thoracic spine in the sagittal plane (Mellin et al., 1991). The justification for measuring extension from a maximally flexed position was that this method is not influenced by neutral kyphosis and difficulties with determining a standardised starting position are negated. The tape measure method also allows for associated lumbar movement to occur, however the thoracic spine is isolated as only the change in distance from T1 to T12 is measured. An alternative method using a HALO device was also applied in this study; however this movement assesses thoracolumbar mobility as there is no attempt to remove lumbar movement.



Figure 15: Assessment of Thoracic Mobility in the Sagittal Plane

A) represents the starting position for the tape measure method; B) end position for tape measure; C) starting position for HALO method and D) end position for HALO method

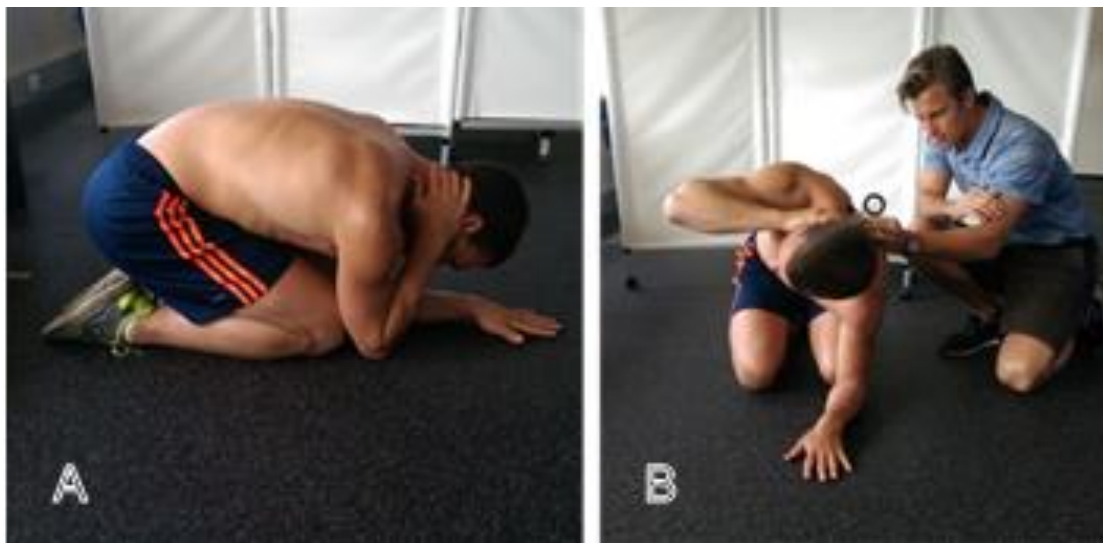


Figure 16: Assessment of Thoracic Rotation using the Lumbar Locked Method

A) Represents the starting position; B) Right thoracic rotation

2.6.1.3.4.2. Thoracic Rotation Method

The method chosen to measure thoracic rotation is known as the lumbar locked position (Johnson et al., 2012). Here the participant is required to assume a four point kneeling position with both knees and hips in maximal flexion Figure 16. The participant then places both elbows on the ground in contact with both knees; the elbows should be flexed at 90 degrees. The participant then places their hand on their neck and rotates the thoracic spine towards this side. The examiner must ensure that the arm that is not in contact with the ground maintains the same starting position (shoulder flexed to 90 degrees and hand on neck) throughout the rotation movement. An inclinometer is placed on T1/2 and the measurement is recorded at end range of rotation; both left and right rotation is measured. The verbal instruction involved asking the participant to, "Rotate their trunk while keeping one elbow fixed on the floor".

The criteria for "failure" of the required movements involved the participant being unable maintain full flexion of the hips and knees or maintain the contralateral elbow on the ground or the angle of the ipsilateral elbow was not the same as the starting position. If this occurred the participant was corrected and the movement was repeated.

Each participant presented on two sessions on the same day for testing. The evaluators obtained two active ROM measurements with the inclinometer for each session. The two sessions were separated by a time period of 3 hours and subjects were instructed to avoid any stretching or exercise during this time period.

2.6.1.3.5. Data Analysis

Data analysis was performed with SPSS version 20.0. Descriptive statistics including means, standard deviations and ranges were calculated for each measure and for each session. The initial purpose of this study was to determine the reliability of two clinical methods to determine thoracic ROM. The intraclass-correlation coefficient (ICC) was used to reflect the reliability of the measures (Lexell & Downham, 2005). Fleiss (1986) recommended that ICC values $>.75$ represent "excellent reliability" and values between $.4-.7$ represent "fair to good reliability". A two way mixed model were used to determine reliability between measure one and measure two within the same

session ($ICC_{3,1}$). The inter-session reliability was determined between the average of two measures from each session ($ICC_{3,2}$). This model was used because this investigator was the only tester of interest.

ICC values may be high despite poor trial to trial consistency if the inter-subject variability is too high (Lexell & Downham, 2005). To negate this issue the standard error of measurement (SEM) was used as this is not affected by inter-subject variability. The SEM was calculated using the formula $SEM = \sqrt{WMS}$ (Hopkins, 2000; Lexell & Downham, 2005), where WMS is the mean square error term from the analysis of variance. The smallest real difference (SRD_{95}) was also calculated to determine the magnitude of change that would exceed the threshold of measurement error at the 95% confidence level. The formula used was $SRD = 1.96 \times SEM \times \sqrt{2}$ (Safrit & Wood, 1989). To calculate the level of agreement between sessions a one-sample *t* test was used which determines if any systematic bias was present. To calculate the 95% levels of agreement the formula $mean\ diff - 1.96 \times SD$ was applied. Data was then presented graphically through the use of Bland Altman plots.

The second purpose of this study was to quantify thoracic mobility in elite surfers. An independent *t*-test and the non-parametric Mann Whitney U test were used for comparative analysis between the elite surfing group and the age and gender matched controls.

2.6.1.4. Results

2.6.1.4.1. Thoracic Mobility in the Sagittal Plane

The within and between session intra-rater reliability analysis with ICC values, SEM and SRD are displayed in Table 23. ICC values ranged between .96 - .99 and were all within excellent reliability ranges ($> .75$) according to recommendations of Fleiss (1986).

Table 23: Within and Between Session Intra-Rater Reliability Analysis for Thoracic Mobility Methods in the Sagittal Plane

	ICC average	95% CI of ICC	SEM†	SRD†
Tape measure (within session)	.96	.91 – .98	0.44	1.22
Tape measure (Between session)	.95	.88 – .98	0.49	1.36
HALO (within session)	.99	.97 – .99	2.92	8.08
HALO (between session)	.98	.95 - .99	3.86	9.21

†Tape measure values are in centimetres; and HALO measures are in degrees.

In order to determine agreement between session one and session two Bland Altman plots were conducted for both the tape measure method (Figure 17) and the HALO method (Figure 18). Firstly for the tape measure method the differences between session one and session two were analysed using a one sample t -test; assuming the mean difference would be zero (null hypothesis). A mean difference of 0.05 cm was calculated which was insignificant ($p = .70$, $t = 0.39$) confirming the null hypothesis. This was also the case for the HALO method with a mean difference of 1.42 degrees ($p = .19$).

Figure 17 presents a Bland Altman plot of the tape measure method for between session reliability. The middle horizontal line presents the mean difference between session one and session two (0.05 cm) and the lines above and below are the 95% confidence limits; these were calculated off the formula $\text{mean diff} \pm 1.96 \times \text{SD}$. A regression analysis revealed no significant ($p = .43$) bias in the distribution of data points either side of the mean difference between session one and two.

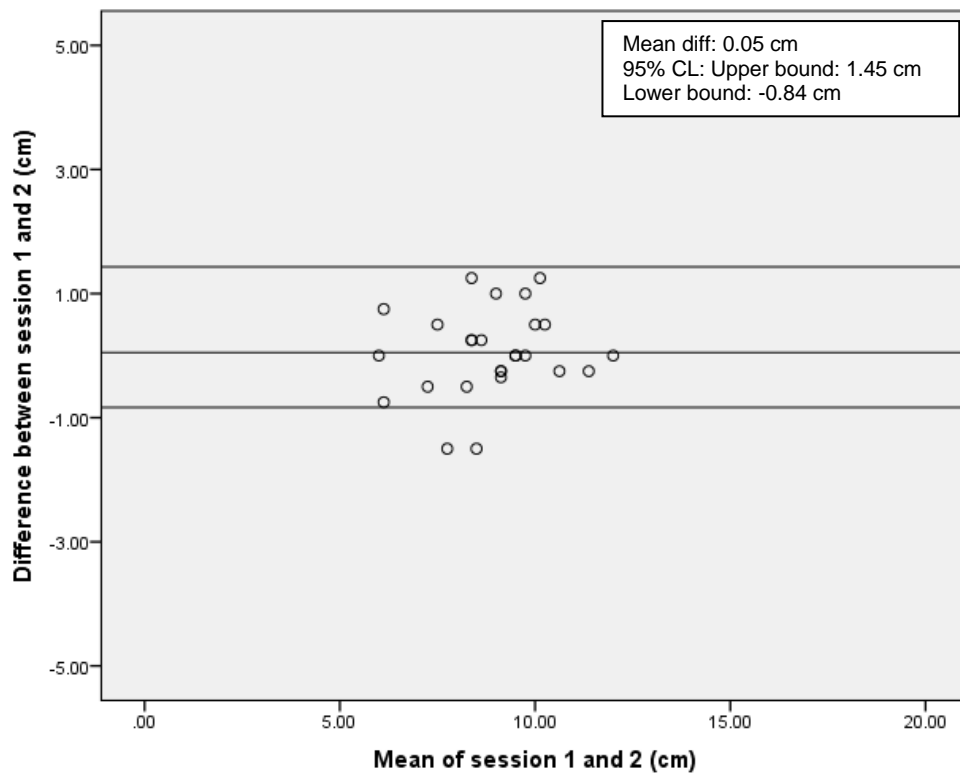


Figure 17: Bland Altman Plot for Between Session Intra-Rater Reliability for the Tape Measure Method

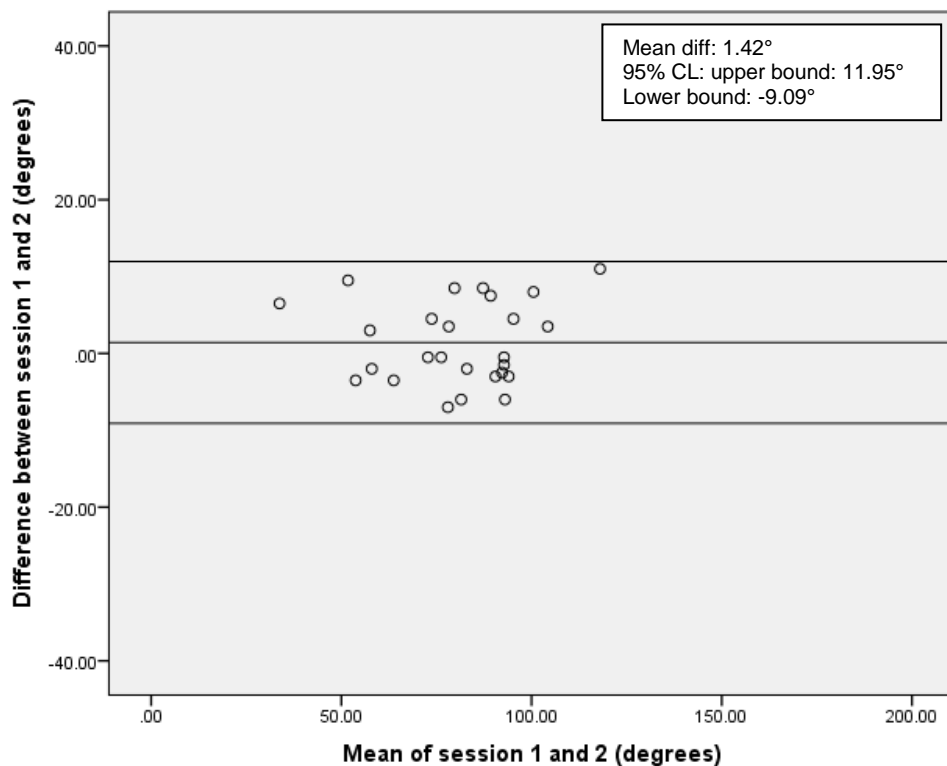


Figure 18: Bland Altman Plot for Between Session Intra-Rater Reliability for the HALO Method

2.6.1.4.1.1. Elite Surfers versus Age and Gender Matched Controls

An independent *t*-test revealed a significant difference ($p = .01$, $t = 2.76$) between the ages of the control group from the reliability study and the elite surfing group. Due to this difference those greater than 34.1 years old were removed from both groups. It was also determined to remove all females from both groups to allow for gender and aged matched groups providing a total of 15 elite surfers and 11 age and gender matched controls. An independent *t* test was then performed and revealed no significant differences ($p = .50$) between the ages of the control and competitive surfing groups ($M = 25.54$, $SD = 3.86$ vs.. $M = 26.47$, $SD = 4.59$ years, respectively). This was also applied to the thoracic rotation data to ensure age and gender matched groups ($M = 25.67$, $SD = 3.70$ vs.. $M = 26.47$, $SD = 4.59$ years, respectively).

A Shapiro-Wilks test ($p > 0.05$) (Shapiro & Wilk, 1965) and a visual inspection of their histograms, normal Q-Q plots and box plots showed that the extension values were approximately normally distributed for both the surfing and control groups; with skewness of 0.39 ($SE = 0.66$) and kurtosis of 0.07 ($SE = 1.28$) for controls and a skewness of 0.78 ($SE = 0.58$) and a kurtosis of -0.57 ($SE = 1.12$) (Barnes, 1998; Cramer, 2012). Once the groups were aged and gender matched and the data was determined to be normally distributed; an independent T-test showed no differences in extension between the groups (Table 24).

Table 24: Comparison of Thoracic Mobility in the Sagittal Plane Between Elite Surfers and Age and Gender Matched Controls

	Surfer (n = 15)*	Controls (n = 11)*	Significant Difference ($p \leq .05$)
Tape measure method (cm)	9.86 ± 1.25	9.20 ± 1.44	$t = 1.24$ ($p = .23$)
HALO method (degrees)	81.33 ± 16.43	78.09 ± 15.24	$t = -0.51$ ($p = .61$)

*Means and standard deviations (\pm) are presented

2.6.1.4.2. Thoracic Rotation

Below Table 25 presents the within and between session intra-rater reliability analysis with ICC values, SEM and SRD calculated. ICC values ranged between 0.96 - 0.98 and were all within excellent reliability ranges (> 0.75). Between session ICC values were consistently lower and SEM and SRD values were consistently higher compared to within session values.

Table 25: Within and Between Session Intra-Rater Reliability Analysis for Thoracic Rotation Methods

	ICC average	95% CI of ICC	SEM	SRD
Left thoracic rotation: Inclinator (within session)	.98	.96 – .99	1.91	5.29
Left thoracic rotation: Inclinator (between session)	.95	.89 – .98	3.04	8.43
Right thoracic rotation: Inclinator (within session)	.98	.95 – .99	3.38	9.36
Right thoracic rotation: Inclinator (between session)	.97	.93 – .98	2.94	8.16
Total ROM: Inclinator (within session)	.98	.97 – .99	3.72	10.33
Total ROM: Inclinator (between session)	.96	.91 – .98	5.37	14.89

Absolute agreement between session one and two was also determined; with the differences between session one and session two for total ROM analysed using a one-sample *t*-test. Total ROM and between session values were chosen as this would most likely be used in the clinical setting. A mean difference of 0.53 degrees was calculated which was insignificant ($p = .71$, $t = 0.38$) confirming that no fixed bias was present.

Figure 19 presents a Bland Altman plot for session one and two. The middle horizontal line presents the mean difference between session one and session two (0.53) and the lines above and below are the 95% confidence limits; these were calculated off the formula $\text{mean diff} \pm 1.96 \times \text{SD}^{\text{DIFF}}$. A linear regression analysis revealed no significant ($p = .89$) bias in the distribution of data points either side of the mean difference between session one and two.

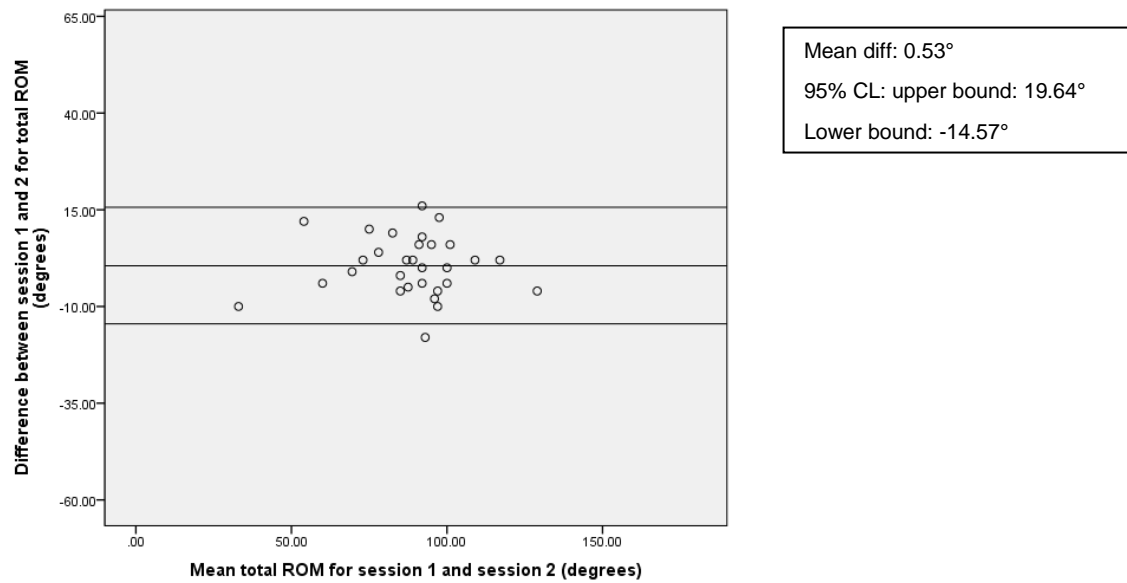


Figure 19: Bland Altman Plot for Between Session Intra-Rater Reliability for Thoracic Rotation

2.6.1.4.2.1. Elite Surfers versus Age and Gender Matched Controls

The thoracic ROM for the control group data was not normally distributed; this was determined through a Shapiro-Wilks test ($p = .03$). The Mann Whitney U test was the non-parametric test selected to determine if significant differences existed between groups; measures from session one were averaged and used for both groups (Table 26). Symmetry between left and right rotation was also determined for the elite surfing group through paired t -tests with no significance found ($p = .73$, $t = 0.36$) between either movement. Table 26 also reveals the elite surfing group to have significantly ($p < .001$) greater thoracic rotation (right, left and total) compared to the control group.

Table 26: Comparison of Thoracic Rotation Between Elite Surfers and Age and Gender Matched Controls

	Surfer (n = 15)*	Controls (n = 12)*	Significant Difference ($p \leq .05$)*
Thoracic left rotation (degrees)	64.01 \pm 8.89	40.33 \pm 11.90	$U = 3.00$ ($p < .001$ two tailed)*
Thoracic right rotation (degrees)	63.06 \pm 10.58	41.50 \pm 10.77	$U = 13.50$ ($p < .001$ two tailed)*
Total Thoracic rotation (degrees)	127.13 \pm 16.21	81.33 \pm 21.10	$U = 4.00$ ($p < .001$ two tailed)*

*Means and standard deviations (\pm) are presented

2.6.1.5. Discussion

The initial findings from this study provide useful information for clinicians wanting to assess or screen the thoracic spine in the sagittal or horizontal planes. As previously mentioned quantifying thoracic extension provides several challenges for the clinician and hence the large disparities in ROM expressed in the research to date (Crawford & Jull, 1993; Edmondston et al., 2012; Kellis et al., 2008; Kuo et al., 2009). Position, devices used and the significant disparities in ROM expressed greatly differ between studies. This lack of consensus was a primary reason for exploring a new clinically applicable method that could be applied in a surfing cohort.

This study applied a tape measure method, which uses a distraction technique and quantifies thoracic mobility in the sagittal plane (extension from a maximally flexed position). Neutral kyphosis does not influence the starting position as with previous inclinometry studies (Crawford & Jull, 1993; Edmondston et al., 2012; O'Gorman & Jull, 1987). The primary reason for eliminating the impact neutral kyphosis has on the range of extension was our observations of lower neutral kyphosis values ($M = 27.7$, $SD = 8.7$ degrees) in an elite surfing cohort compared to previous age and gender matched published data (Lewis & Valentine, 2010; O'Gorman & Jull, 1987). Kyphosis was determined through the inclinometer methods previously described by (Lee et al., 2003; Lewis & Valentine, 2010).

The hypothesised reason for this decreased neutral kyphosis may be due to the activity requirements of surfing with approximately 50% of a surfing session spent in the prone position paddling (Farley et al., 2012b). In order to have adequate arm clearance thoracolumbar extension needs to occur. This constant active extension may provide active and passive adaptations at the thoracic spine reducing the neutral thoracic kyphosis. A minimal neutral kyphosis may under-reflect the amount of thoracic extension. Therefore, to negate this issue extension commenced from a maximally flexed position. This movement is influenced by the amount of thoracic flexion achieved at the starting position and presents a value that reflects thoracic mobility in the sagittal plane or total thoracic ROM (flexion plus extension).

When reviewing both methods for thoracic mobility in the sagittal plane, within and between session reliability values are all within the excellent ranges ($ICC > .70$) according to Fleiss (1986). Systematic bias was also ruled out through one sample t -tests; this was considered an important statistical procedure as high correlations do not necessarily equate to agreement between measurements. This can occur due to

large variations in sample data. It needs to be noted that there were no statistical differences between the surfers and the control group for both thoracic and thoracolumbar mobility in the sagittal planes. Rationale for this may be attributed to the possibility that excessive thoracic or thoracolumbar mobility in the sagittal plane is not required in a surfing cohort, but reduced neutral kyphosis is more apparent. Another possibility may be attributed to the testing position; even though the sitting position may provide bias to the thoracic spine it may not replicate the demands of surfing.

Although no statistical difference was noted; both movements were greater in the surfing group suggesting clinical rationale for maintaining thoracic mobility in the sagittal plane. It could also be argued that a limitation in thoracic mobility in the sagittal plane (dysfunction) may prevent adequate rotation of the thoracic spine. Therefore maintaining mobility in both the sagittal and horizontal planes is essential in an elite surfing cohort.

The secondary aim of this study was to review the reliability of a thoracic rotation method and compare this data to a surfing cohort. Through visual observation it is clear thoracic rotation is imperative during surfing manoeuvres; however quantifying the amount of thoracic rotation in this cohort was not established previously. This study revealed excellent within and between session ICC values (.95 – .98) and revealed no fixed bias between sessions ($p = .71$, $t = 0.38$). It most importantly presented the range of thoracic rotation in an elite surfing cohort which was significantly greater than the comparative group (Table 26). When comparing the control group mean rotation values to previous research by Johnson et al. (2012) using the identical inclinometer method the results are very similar (40.80 vs. 44.76 degrees, average age 31 vs. 24 years respectively). It also needs to be pointed out that the elite surfing cohort mean ($M = 63.57$ degrees) appears significantly greater to the results of Johnson et al. (2012).

Of interest there was no significant difference between left and right rotation in the elite surfing group ($p = .73$). A surfer is often required to rotate in both directions during a surfing session and therefore one would assume that the activity requirements promote this symmetry. This information may be useful for clinicians dealing with surfers; where by identified asymmetry or inadequate ROM provide direction for treatment and conditioning exercises.

The strengths of this study need to be noted and are evident in the methodology. An attempt was made to blind the rater by having a recorder present; the rater was

competent in the assessment procedures and had received adequate training and a standardised warm-up was given in an attempt to reduce any learning effects (systematic bias). The limitations of this study include the lack of randomisation of thoracic extension and rotation movements; this reduces the chances of potential learning effects. Inter-rater reliability was not assessed and therefore these results need to be viewed with caution when measuring between clinicians. Although this study had an adequate sample size for the reliability component; the sample size for the comparative and elite surfing group provides limitations when generalising results. The data for the control group for thoracic rotation was not normally distributed and highlights the need for a larger group size for comparative analysis. Another limitation of this study is the absence of a female surfing cohort, future research should look to include this cohort.

2.6.1.6. Conclusion

This study has introduced a new clinically applicable method to assess thoracic mobility in the sagittal plane and has revealed excellent intra-rater reliability values for the lumbar locked method for thoracic rotation. To our knowledge this is the first research study to quantify thoracic mobility in an elite surfing cohort; of note this study found surfers to possess significantly more thoracic rotation than age and gender matched individuals. This information may provide clinicians, coaches and athletic trainers with imperative information regarding the importance of maintaining adequate thoracic rotation and symmetry. From a screening perspective thoracic rotation should be assessed for performance purposes and to limit the potential for injury in this or surrounding regions.

The authors declare no external funding or sponsorship was granted within this project. All equipment selected was chosen due to its practical use in the clinical setting.

2.6.2 ASSESSMENT OF SHOULDER RANGE OF MOTION IN PRONE VERSUS SUPINE: A RELIABILITY AND CONCURRENT VALIDITY STUDY

The results of Study 2 for determining the reliability of shoulder ER and IR in a prone position are presented in the following paper. This is an Accepted Manuscript of an article published by Taylor and Francis in *Physiotherapy Theory and Practice* on September 11, 2015, available online: <http://www.tandfonline.com>; DOI: 10.3109/09593985.2015.1027070.

Furness, J., Hing, W., Abbott, A., Sheppard, J. M., & Climstein, M, Johnstone, S. (2015). Assessment of shoulder range of motion in prone versus supine: a reliability and concurrent validity study. *Physiotherapy Theory and Practice*, 31 (7), 489-495.

2.6.2.1. Abstract

Background: As swimming and surfing are prone dominant sports, it would be more sport specific to assess in this position. Objectives: To determine the reliability of the inclinometer and HALO in supine and prone and the concurrent validity of the HALO. Concurrent validity is based on the comparison of the HALO and inclinometer. To determine if active range of motion (AROM) differences exists between prone and supine when assessing shoulder internal (IR) and external rotation (ER). Design: Clinical Measurement, reliability and validity. Methods: Thirty shoulders (mean age = 26.8 years) without pathology were evaluated. Measurements were taken in supine and prone with both an inclinometer and HALO device. Results: Active ER ROM in prone was significantly higher than in supine when using both devices. Intra-rater reliability (within and between session) intraclass correlation coefficient (ICC) values ranged between 0.82 - 0.99 for both devices in supine and prone. An ICC test revealed a significant ($p < 0.01$) correlation for both devices in IR and ER movements ($ICC_{3,1} = 0.87$ and $ICC_{3,1} = 0.72$) respectively. Conclusion: This study has shown prone assessment of active ER and IR ROM to be a reliable and appropriate method for prone dominant athletes (swimmers and surfers). In this study greater ER ROM was achieved in prone compared to supine. This finding highlights the importance of standardising the test position for initial and follow up assessments. Furthermore the HALO and inclinometer have been shown to be reliable tools that show good concurrent validity.

2.6.2.2. Introduction

Physiotherapists routinely evaluate joint range of motion (ROM) as part of a musculoskeletal assessment (Riemann, Witt, & Davies, 2011). These measurements are critical in providing baseline measures, diagnosis of disorders and evaluation of treatment through quantifying degree of change (APTA, 2003; Muir et al., 2010). They are also routinely used in screening assessments for athletes to detect asymmetry, abnormality and potentially prevent future injury (Riemann et al., 2011).

It is worthwhile to consider whether assessment of a joint can be carried out in a position that is relevant and specific for the athlete. Researchers are currently undertaking musculoskeletal screening of the shoulder in both recreational and competitive surfers. Meir et al. (1991) performed a time motion analysis of one hour of recreational surfing and found that 50% of the time is spent paddling in the prone position, therefore exploration of a prone shoulder AROM assessment was justified.

Shoulder injuries in a surfing population have been reported in previous literature (Furness et al., 2014; Meir et al., 2012; Nathanson et al., 2002; Taylor et al., 2004) however at present there are no studies which have evaluated joint ROM in this cohort. The current paucity of research which physically assesses shoulder active ROM in a surfing population and the need to perform this in a prone position was the premise for this study. Prior to undertaking physical assessment of the shoulder in a surfing population, a reliable procedure in the prone position needed to be established.

Altered internal (IR) and external rotation (ER) has been associated with the aetiology of shoulder disorders (Lin & Yang, 2006; Lunden, Muffenbier, Giveans, & Cieminski, 2010). Both of these movements are critical when in the prone position during surfing and therefore were the movements which needed to be assessed. These movements can be objectively measured through a number of instruments including a ruler, tape measure, goniometer and inclinometer (Clarkson, 2005). Inclinometers appear superior to other devices as it can be calibrated on the basis of the universal constant of gravity. This enables the starting position to be consistently identified and repeated (Lea & Gerhardt, 1995). The movement of shoulder IR and ER can be performed actively or passively; however active range of motion (AROM) is considered more reliable as this does not rely on the capability of the clinician to determine an end feel (Muir et al., 2010).

An electronic search was undertaken to investigate methodology for assessment of active shoulder ROM for the movements of IR and ER in the prone and supine position. The following databases MEDLINE, CINAHL and EMBASE were searched using the primary search terms (shoulder, range of motion and all synonyms for reliability). Only two research papers were identified which assessed shoulder range of motion in prone (Kolber & Hanney, 2012; Kolber et al., 2009). Both papers assessed shoulder IR in the prone position, however ER was not assessed in the prone position. To our knowledge, there is no available research investigating shoulder ER in prone and the reliability of this movement for use in clinical assessment is yet to be established. Additionally although research exists which examines prone or supine shoulder IR, the methodology, device and sample population provide too many challenges to compare their results.

The absence of data for shoulder ER in prone developed the hypothesis that differences in ROM would be present when compared to supine. This has been previously demonstrated in the hip joint where significant differences existed when comparing mean ER values in sitting versus prone ($M = 36$, $SD = 7$ vs. $M = 45^\circ$, $SD = 10$ degrees) (Simoneau, Hoenig, Lepley, & Papanek, 1998).

Recently a new commercial device known as a HALO digital goniometer is available for clinicians to assess ROM. The HALO uses a magnetic system for movements in the horizontal plane and accelerometers in the sagittal plane. Two lasers are situated on either side of the HALO; this allows specific landmarks to be intersected and ensure correct and repeatable positioning. This device also has a vertical zero mode which ensures a consistent starting position similar to an inclinometer. To our knowledge no published literature exists which has investigated the reliability or validity of this device.

Therefore three key aims were identified; 1) to determine within session and between session intra-rater reliability of the Inclinometer and HALO, for the movements of shoulder IR and ER in the supine and prone positions; 2) to determine whether a ROM difference exists for IR and ER in prone versus supine and 3) to determine the concurrent validity of the HALO device.

2.6.2.3. Methods

2.6.2.3.1. Subjects

Testing was completed on both the dominant and the non – dominant arm; 30 shoulders in total (15 subjects) were tested and the data analysed accordingly to determine within and between session intra-rater reliability. A sample size of 15-20 is often used in reliability studies, however 30 or greater is required to form practically useful 95% smallest real differences (SRD) (Lexell & Downham, 2005). A total of 40 shoulders (20 subjects) were assessed to determine differences in prone versus supine. Demographic and background information was obtained on all participants; this included age, arm dominance and injury history. Subjects were eligible for the study if they were between the ages of 18 – 75 and able to adopt the starting position (90° of shoulder abduction). The study was approved by the Bond University Ethics committee (RO1610) and informed consent was gained from all participants.

Exclusion criteria included any acute or chronic shoulder pathology that may be aggravated or worsened through repeated testing of IR and ER. Based upon these aforementioned criteria, no participants were excluded. Participants were between the ages of 22 and 48 years with the mean age being 26.8 ($SD = 6.5$) years.

2.6.2.3.2. Raters

The evaluators were two registered physiotherapists, one with seven years of clinical experience in the assessment and treatment of orthopaedic conditions and the other a new graduate physiotherapist. Data collection began in January 2014 and concluded in February 2014 and was performed at a local university. The new graduate performed all measurements and the other physiotherapist recorded; this was done to ensure blinding occurred throughout all measurements.

2.6.2.3.3. Equipment

A standard gravity dependent inclinometer (Universal Inclinometer, model UI01, Performance Attainment Associates, Minnesota, United States) was used for all range of motion measurements. To ensure the gravity dependent inclinometer was set to an accurate zero starting point, a vertical reference was established through the use of a bubble level. This reference point was then used throughout all testing.

The HALO (model HG1, HALO Medical Devices, Australia) device was used for all joint range of motion measures in this study (Figure 20). This device has a “vertical zero mode”, where vertical is zero degrees. Therefore even if the shoulder is starting in a slightly internally rotated position this movement is accounted for. To our knowledge, there is currently no available research investigating the reliability and validity of this device in measuring joint range of motion.

A standard 12 inch, double armed 360 degree goniometer (JAMAR, E-Z Read) was used to establish a standardised patient set up. The goniometer was used to ensure each movement was started from 90° of abduction.



Figure 20: HALO Device

2.6.2.3.4. Design

The two evaluators participated in a one hour formal training session with a musculoskeletal specialist to ensure correct measuring procedures were followed; this was done prior to data collection. Subjects were provided with verbal instructions and performed the required movement three times as a warm-up under the guidance of the assessors. This was completed to minimise the risk of a learning effect. This procedure was standardised for all testing and we believe offered no mobilisation effect.

Active shoulder IR and ER rotation was assessed by two devices (1) an inclinometer 2) HALO) in two different positions (1) prone 2) supine) consistent with the established protocols from Clarkson (2005). An assessor positioned the subject and instructed the movement to be performed and a recorder then read and recorded the joint range of motion ensuring blinding of the assessor. Throughout all testing, the HALO was used in the “vertical zero mode”. The gravity dependent inclinometer was re-calibrated between each change in position. An illustration of the supine and prone set up is presented in Figure 21. Further details of the test positions, manual stabilisation and device placement are found in Appendix 7.

Each participant presented on two sessions on the same day for testing. The two sessions were separated by a time period of three hours and subjects were instructed to avoid any stretching or exercise during this time period.



Figure 21: Testing Set up for Active IR and ER in Prone and Supine

A) IR in Supine with the HALO Device; B) ER in Supine with the Inclinometer; C) ER in Prone with the HALO Device; D) IR in Prone with the Inclinometer)

2.6.2.3.5. Data Analysis

Data analysis was performed with statistical package for the social sciences (version 20.0). Descriptive statistics including means, standard deviations and ranges were calculated for each measure and for each session. The intraclass correlation coefficient (ICC) was used to determine reliability (Lexell & Downham, 2005). Fleiss (1986) recommended that ICC values $> .75$ represent “excellent reliability” and values between $.4 - .7$ represent “fair to good reliability”.

A two-way mixed model were used to determine reliability between measure one and measure two within the same session ($ICC_{3,1}$). The between-session reliability was determined between the average of two measures from each session ($ICC_{3,2}$). This model was used because only the chief investigator was the only tester of interest. ICC values may be high despite poor trial to trial consistency if the inter-subject variability is too high (Lexell & Downham, 2005). To negate this issue the standard error of measurement (SEM) was used as this is not affected by inter-subject

variability. The SEM was calculated using the formula $SEM = \sqrt{WMS}$ (Hopkins, 2000; Lexell & Downham, 2005), where WMS is the mean square error term from the analysis of variance. The smallest real difference (SRD_{95}) was also calculated to determine the magnitude of change that would exceed the threshold of measurement error at the 95% confidence level. The formula used was $SRD = 1.96 \times SEM \times \sqrt{2}$ (Safrit & Wood, 1989).

Paired t - tests were used to determine whether significant differences exist between both shoulder IR and ER in prone versus supine. Intraclass correlation coefficient (ICC) was used to determine the correlation for both devices in IR and ER movements. Linear regression was performed for both devices in IR and ER movements to calculate R squared strength of relationship.

2.6.2.4. Results

Thirty shoulders were assessed (15 subjects, 8 males, 7 females) to determine the reliability of both devices in prone and supine. The overall mean age was 26.8 years ($SD = 6.5$; range 22 to 48 years). Table 27 presents the within session reliability analysis with ICC values, SEM and SRD calculated. ICC values ranged between 0.93 - 0.99 and were all within excellent reliability ranges (> 0.75) (Fleiss, 1986). The SEM and SRD values for the inclinometer in the prone position revealed lower values compared to the HALO in prone.

Table 28 presents the between session reliability analysis with ICC, SEM and SRD values calculated. Lower ICC values (.82 - .96) are represented compared to table one however they all are still with the excellent range. The SEM and SRD values are lower for the inclinometer in both positions compared to the HALO.

Table 27: Within Session Reliability Analysis for Shoulder Prone and Supine Assessment

			ICC (average)	95% CI of ICC	SEM*	SRD*
Prone	Inclinometer	ER	.98	.95 - .99	1.5	4.2
		IR	.99	.98 - .99	1.5	4.2
	HALO	ER	.97	.95 - .99	1.9	5.3
		IR	.99	.97 - .99	2.0	5.3
Supine	Inclinometer	ER	.93	.86 - .97	2.4	6.7
		IR	.98	.96 - .99	1.8	5.0
	HALO	ER	.97	.93 - .99	2.4	6.7
		IR	.98	.94 - .99	2.2	6.1

Abbreviations:* refers to all values in degrees; ICC, intraclass correlation coefficient; SEM, standard error of measurement; SRD, smallest real difference at the 95% confidence level; IR, Internal Rotation; ER, External Rotation

Table 28: Between Session Reliability Analysis for Shoulder Prone and Supine Assessment

			ICC (average)	95% CI	SEM*	SRD*
Prone	Inclinometer	ER	.82	.63 - .91	3.5	9.7
		IR	.96	.91 - .98	3.4	9.4
	HALO	ER	.85	.69 - .93	4.2	11.6
		IR	.96	.92 - .98	3.3	9.2
Supine	Inclinometer	ER	.88	.74 - .94	3.2	8.9
		IR	.96	.91 - .98	2.7	7.5
	HALO	ER	.93	.85 - .97	3.7	10.3
		IR	.84	.66 - .92	5.8	16.1

Abbreviations: * refers to all values in degrees; ICC, intraclass correlation coefficient; SEM, standard error of measurement; SRD, smallest real difference at the 95% confidence level; IR, Internal Rotation; ER, External Rotation

Bland Altman plots for the prone position using the inclinometer present between session intra-rater values for ER and IR (Figure 22 and Figure 23). The differences between measurements from the two test occasions are plotted against the mean of the two test occasions for each shoulder measured; the 95% confidence intervals are also included. Both Figure 22 and Figure 23 reveal an unbiased agreement between session one and two for both ER and IR in the prone position.

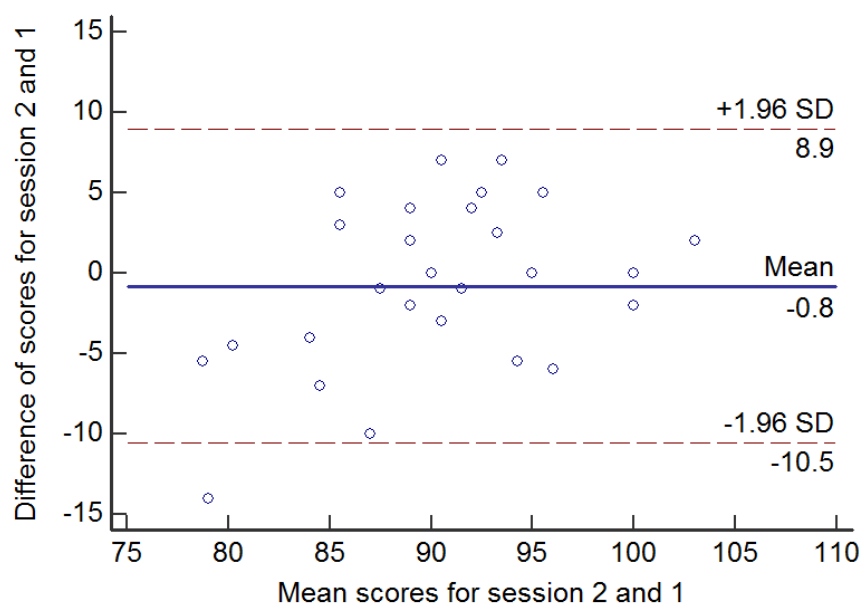


Figure 22: Bland Altman Plot for Between Session Reliability for Prone ER Using the Inclinometer

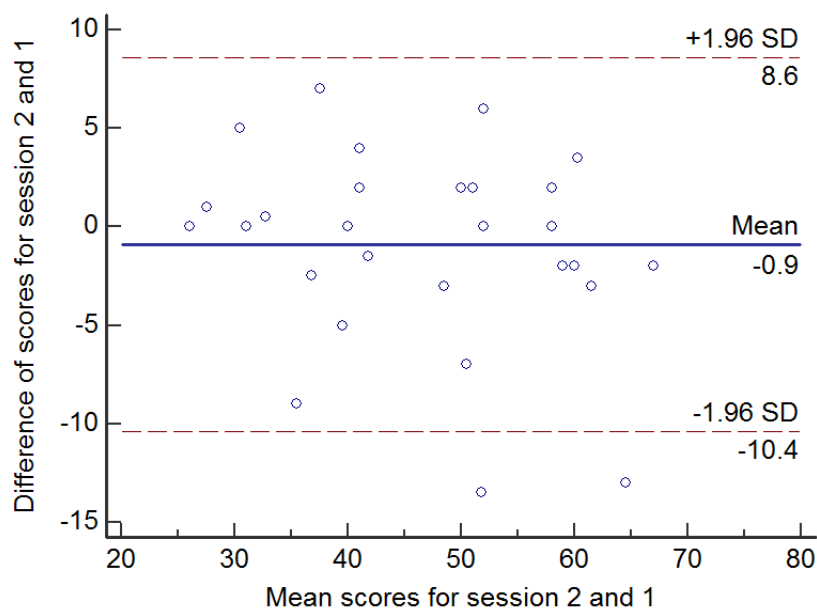


Figure 23: Bland Altman Plot for Between Session Reliability for Prone IR with Using Inclinometer

2.6.2.4.1. Prone versus Supine

A total of 40 shoulders (20 subjects, 12 males and 8 females) were assessed to determine if differences exist between prone and supine. The mean age was 26.4 years ($SD = 5.8$, range 22 to 48 years). Table 29 presents the mean of measure one and two for session one in both prone and supine positions. ER in prone was significantly ($t = 3.0$, $p = .005$) higher than in supine ($M = 89.7$, $SD = 7.2$ vs. $M = 85.4$, $SD = 6.4$ degrees) when using an inclinometer. This was also the case for the HALO device where ER in prone was significantly ($t = 2.4$, $p = .02$) higher than in supine ($M = 89.2$, $SD = 8.6$ ° vs. $M = 85.1$, $SD = 10.0$ degrees). IR with the inclinometer and HALO device did not reveal significant differences despite a change in position.

To determine the level of agreement all data obtained for ER in prone were compared against ER in supine; the differences between individual data sets were analysed using a One-Sample t – test. The results revealed a mean difference of 3.1degrees between the two test positions which was statistically significant ($p = 0.01$); this indicates the lack of agreement between the two test positions for ER. This is assuming that the null hypothesis would result in a mean difference of zero. The same procedure was conducted for IR with a mean difference of -0.33 degrees which was statistically insignificant ($p = .82$) indicating agreement between the two test positions for IR. A regression analysis revealed no significant ($p = .20$) bias in the distribution of data points either side of the mean difference for IR.

Table 29: A Comparison of Mean scores for Prone versus Supine from Session 1

		Prone (degrees)	Supine (degrees)	Significant Difference ($p \leq .05$)
Inclinometer	ER	89.7 (7.2)	85.4 (6.4)	.005*
	IR	46.7 (11.4)	46.9 (9.6)	.94
HALO	ER	89.2 (8.6)	85.1 (10.0)	.02*
	IR	47.7 (11.7)	48.2 (10.3)	.81

*Indicates statistical significance ($p \leq .05$); all values are presented as mean and standard deviation (\pm).

2.6.2.4.2. Concurrent Validity of HALO Device

Concurrent validity was based on the comparison of the HALO and inclinometer. All ICC values for within session and between sessions were within excellent ranges ($> .75$) in prone and supine. A correlational analysis was therefore performed regardless of position. This analysis took the combined average from both sessions and both positions and compared the values from the inclinometer against the HALO. Intraclass correlation coefficient (ICC) revealed a significant ($p < .01$) correlation for both devices in IR and ER movements ($ICC_{3,1} = .87$ and $ICC_{3,1} = .72$ respectively). The squared correlation coefficient (r^2) for ER was .35 and IR .59 indicating a stronger relationship for IR for the two devices. An illustration of the linear relationship between the two devices is presented in (Figure 24 and Figure 25).

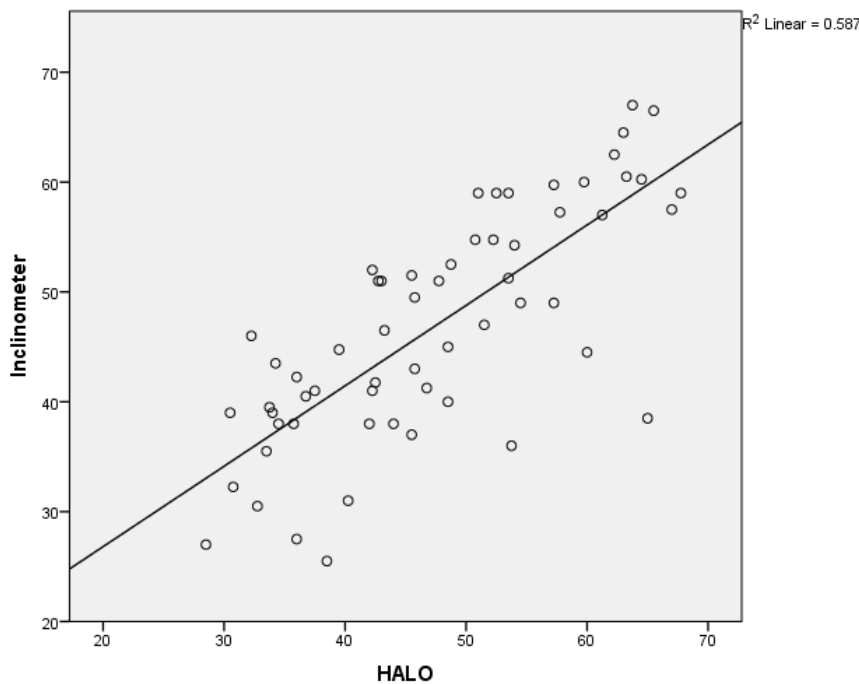


Figure 24: Scatterplot of Internal Rotation Scores for the HALO and Inclinometer

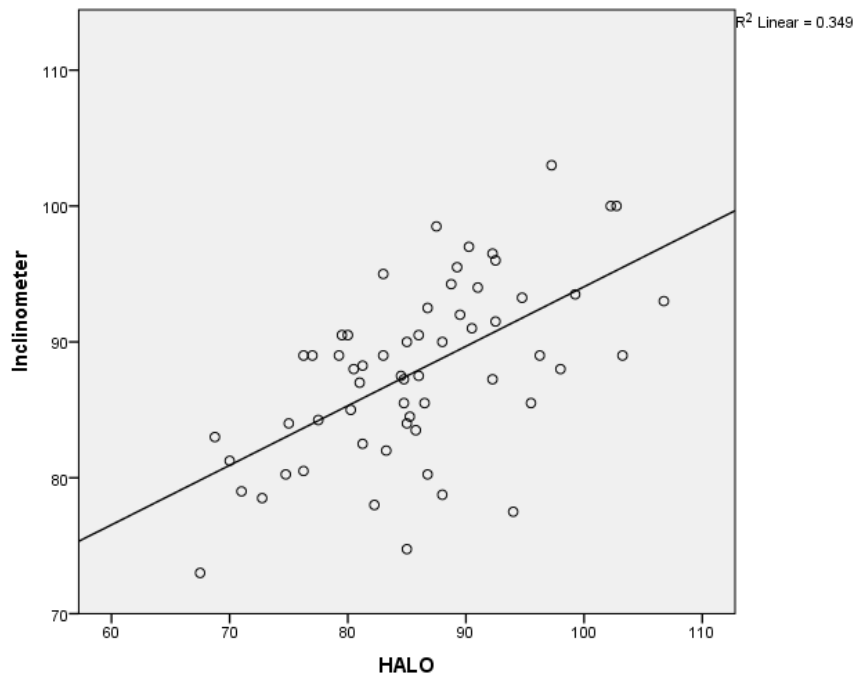


Figure 25: Scatterplot of External Rotation Scores for the HALO and Inclinometer

2.6.2.5. Discussion

While several clinical measurements are available to measure shoulder ROM, goniometry and inclinometers remain the most widely used (Roy & Esculier, 2011). Previous research has assessed active shoulder IR and ER using an inclinometer (Green, Buchbinder, Forbes, & Bellamy, 1998; Hoving et al., 2002; Kolber & Hanney, 2012; Kolber et al., 2009). Two of these papers used a prone position however this was performed for IR only (Kolber & Hanney, 2012; Kolber et al., 2009). To our knowledge no paper has compared IR and ER in prone and supine. It would seem more logical to assess prone dominant athletes such as surfers in the prone position as this is specific to the sport.

The initial aim was to determine the reliability of both the HALO and inclinometer. With regards to the inclinometer this current study revealed excellent within session (ICC .93 – .99) and between session reliability (ICC .82 – .96). Previous research (Green et al., 1998; Hoving et al., 2002; Kolber & Hanney, 2012; Kolber et al., 2009) assessing reliability of inclinometry for shoulder active range of motion has reported varied results with ICC values ranging from .32 – .99. This current study's findings exceed previous research by both Green et al. (1998) (ICC .75 – .82) and Hoving et al. (2002) (ICC .32- .43) and are comparable to results by (Kolber et al., 2009) (.96 – .99).

A thorough literature search revealed no published research investigating the reliability and/or validity of the HALO device. The current results indicated excellent within session (ICC = .97 – .99) and between session reliability (ICC = .84 – .96) for the HALO device. As this is a portable device (~\$259.00 US currency), this new information offers clinicians an alternative assessment tool in measuring active shoulder internal and external rotation in prone or supine. It must also be noted that higher SEM and SRD values were associated with the HALO when compared with the inclinometer (Table 27 and Table 28). This was predominantly seen in supine when considering IR (inclinometer SRD = 7.5, HALO SRD = 16.1). This may be attributed to difficulty in maintaining the HALO against the lateral forearm whilst also palpating for any humeral head movement with the free hand. When performing this measurement with the inclinometer, the device is easier to hold in one hand and maintain its position on the distal forearm. This is seen through higher ICC values and lower SEM and SRD values for the movement and position.

The secondary aim of this study was to determine whether discrepancies exist in shoulder ER and IR ROM in a prone versus supine position. Results revealed a significant difference in ER in prone versus supine when using either device. IR showed no significant differences between prone and supine. These findings show a distinct trend for the assessment of shoulder ER regardless of device. The hypothesised reasons for the greater ER in prone compared to supine in this current study may be attributed to the reduced scapula compression in the prone position. Previous research has illustrated a reduction in shoulder ROM the more the scapula is stabilised and or compressed (Lunden et al., 2010). When in supine, the scapula is indirectly compressed and stabilised through direct pressure from the bed. Although scapula position is controlled for in the prone position through a standardised testing protocol, there is no direct pressure from the bed to compress and add stability to the scapula. Secondly it could be speculated that an increased muscular effort in prone may occur as the participant attempts to overcome this anti-gravity position. In prone, there may be greater co-contraction of the peri-scapula muscles (rhomboids, mid/lower traps) in conjunction with the external rotators (teres minor, infraspinatus). This may lead to greater muscular recruitment and therefore greater range of motion.

The premise for this study was to design a sport specific screening method for the shoulder. These results have indicated the need to assess ER in a consistent position. Bearing this in mind these results would indicate a surfer should be assessed in a prone position. Additionally a clinician may choose to utilize the prone position to assess/ screen functional stability and structural restriction around the

shoulder; especially considering that ER is assisted by gravity in the supine position. One could assume that a ROM greater than the normative values attained from uninjured surfers could clear the joint for functional stability and of any structural restriction. A reduction of ER in the prone position could indicate further testing around the shoulder is needed. It is imperative that normative values are attained from uninjured surfers to determine the appropriate ROM to clear the shoulder. It also needs to be noted that other prone dominant sports such as swimming could utilise this prone position to assess shoulder ER.

Results for IR ROM (46.6 degrees) are similar to previous published research which has specifically looked at prone IR (Kolber et al., 2009) 43 and 55 degrees respectively. Unfortunately, both studies did not assess ER in prone therefore comparisons for this movement cannot be made.

The third aim was to determine the validity of the HALO device. Inclinometers are widely used and accepted in clinical practice and therefore were the benchmark to determine the concurrent validity for the HALO device. Figure 24 and Figure 25 represent the linear relationship between the two devices. A significant correlation was identified through ICC test (IR = .87, ER = .72) assuring the HALO and inclinometer are measuring the same movement.

There are several limitations that exist in this current study. Firstly, it was difficult truly blinding the tester when using the HALO device. This was due to the large digital display and having to wait 2-3 seconds for the device to settle. As inter-rater reliability was not assessed, this needs to be recognised when applying these results to clinical practice especially when more than one clinician is treating the same patient. Finally, a standardised approach should be adopted to ensure reproducible effort by the patient between sessions, however this is extremely difficult to control.

2.6.2.6. Conclusion

This research has identified that greater ER is achieved in prone compared to supine regardless of device. Bearing this in mind, clinicians need to be aware of this when performing initial and follow up assessments and determining change. These findings also stress the need for established norms in the prone position and in a surfing or swimming population where ROM may exceed non-prone dominant athletes. Prone assessment was also a reliable position to assess shoulder range of motion. It would seem more logical to adopt this sport specific position when working with prone dominant athletes (surfing or swimming). Finally, as a significant correlation exists between the HALO and inclinometer; this supports the use of either device in clinical practice as a reliable and valid tool.

The authors declare no external funding or sponsorship was granted within this project. All equipment selected was chosen due to its practical use in the clinical setting.

CHAPTER 3: PROFILING

3.0.1. Preface

This chapter presents Study 3; this study implements the Surf Specific Screen in recreational and competitive surfers. Figure 26 provides an outline of Chapter 3.

This chapter relates to the third aim of this thesis, “To provide a comprehensive musculoskeletal and physiological profile of a recreational and competitive surfer”.

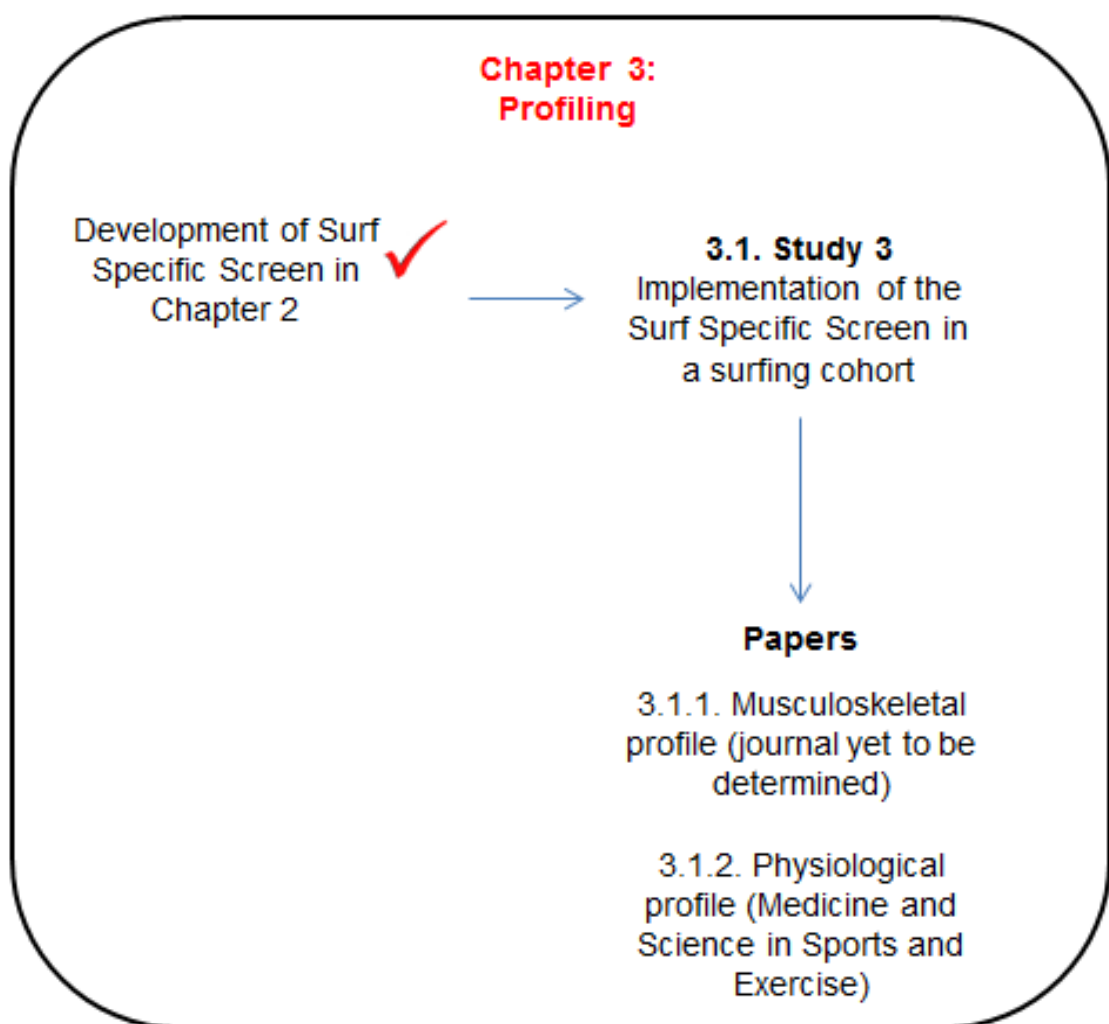


Figure 26: Outline of Chapter 3

3.1. STUDY 3: PROFILING

Study 3 involves the implementation of the Surf Specific Screen in a recreational and competitive surfing cohort. An outline of the surf specific screen template is found in Appendix 4. The methodology of the musculoskeletal component in the Surf Specific Screen can be found in Appendix 3. The methodology for the physiological and body composition assessment can be found in section 3.1.2.

The results of Study 3 are presented in two papers; section 3.1.1 is centred on the musculoskeletal profile and section 3.1.2 is centred on the physiological profile. Due to the large number of variables it was decided to present the physiological and musculoskeletal components separately. Additionally, not all subjects underwent both elements of screening. A recent collaboration with California State University (San Marcos) enabled the addition of subjects who had undergone physiological assessment but not musculoskeletal assessment. Ideally, an athlete would undergo both forms of testing to provide a comprehensive profile and a holistic approach to treatment, prevention and to enhance performance.

This study received ethics from the Bond University Human Ethics Committee and can be found in Appendix 1. The results of this study are presented in two papers in section 3.1.1 and 3.1.2.

3.1.1. MUSCULOSKELETAL PROFILE OF RECREATIONAL AND COMPETITIVE SURFERS

3.1.1.1. Introduction

It is well known that training and taking part in a sport results in physical and physiological adaptations that can bring about positive changes in both strength and flexibility (Probst et al., 2007). Conversely it can result in negative adaptations by creating muscle and flexibility asymmetries and therefore increase the risk of developing acute and chronic injuries (Wanivenhaus et al., 2012). Musculoskeletal conditions are currently the leading cause of disability in Australia (Murray et al., 2012). There is now a growing emphasis in sport to produce positive health results and maintain high participation levels. With sports medicine, this is achieved by minimising injury, refining rehabilitation and enhancing performance (Spurrier, 2015). Screening measures are implemented to ensure the above outcomes are achieved.

Sport specific screening commonly involves an analysis of body type, muscle length and strength testing and functional assessment. Screening can also utilize specific fitness testing that attempts to replicate the energy systems used in the particular sport being assessed (Pelham & Holt, 1995). Testing measures must be specific to the sport the athlete participates in; however, methods used must be standardised and shown to be reliable and valid. The premise behind sports specific screening is three fold; 1) to identify limitations and or asymmetries in joint ROM and or muscular strength; 2) prevent current and further injury and 3) provide direction for coaches and clinicians designing training programs.

Each sport has different requirements on various joints; therefore sports specific screening needs to assess regions which are under stress and or prone to injury (O'Connor et al., 2013). The sport of surfing has unique requirements; when paddling the shoulders and upper spine are subject to stress; however when standing and actually riding the wave, the lower spine and lower limbs are under strain (Everline, 2007). The most recently published injury epidemiological study by Furness et al. (2015) identified the shoulder (16.4%), ankle (14.6%) and head (13.3%) regions as the most prone locations for an acute injury. The incidence proportion (total number of injured surfers divided by the total number of surfers) for acute injuries sustained within a 12 month period was calculated to be approximately 1 in 3 recreational

surfers and 1 in 2 competitive surfers. The same authors identified the lower back (23.2%), shoulder (22.4%) and knee (12.1%) regions as the most prevalent locations for chronic injuries (Furness et al., 2014).

Understanding injury incidence location and causes are the initial steps to be taken when dealing with injury prevention in any sport (Vanmechelen et al., 1992). To go beyond analysing injury epidemiology a physical assessment is essential. Conducting such an assessment allows for the identification of asymmetries, detects strengths and weaknesses and ultimately provides a profile of this type of athlete. Understanding a profile of an athlete may assist with providing baseline norms for individual cohorts (competitive and recreational), be used to identify if an athlete is above or below the base line norms and thus enhance performance or provide rehabilitation direction. Therefore, the purpose of this study was to implement a surf specific screen on both competitive and recreational surfers and subsequently provide a musculoskeletal profile.

3.1.1.2. Methods

3.1.1.2.1. Subjects

A total of 42 recreational and competitive surfers ($M = 26.09$, $SD = 4.75$ years; range 19 to 36 years) were involved in this study; 23 were currently or had previously been competing either on the World Qualifying Series (WQS) or the World Championship Tour (WCT). The remaining 19 surfers were classed as recreational. Seven surfers were female and 35 were males. Key physical demographics of individual cohorts is summarised in Table 30. Ethics was granted through the Bond University Human Research Ethics Committee (RO1610).

3.1.1.2.2. Raters

A physiotherapist with over eight years of clinical experience conducted all testing. Prior to the commencement of this study training with a senior physiotherapist with over 20 years of clinical experience was undertaken. This was done to ensure the correct technique was applied for each individual clinical test.

3.1.1.2.3. Experimental Equipment

An extensive effort was made to ensure equipment used within the musculoskeletal component of the surf specific screen was accessible to clinicians. Unfortunately being able to adequately assess body composition using a 'gold standard' assessment tool requires extensive equipment which is not as accessible to clinicians.

3.1.1.2.3.1. Dual-Energy X-Ray Absorptiometry

Dual-Energy X-Ray Absorptiometry (DEXA) has traditionally been used in a clinical setting to measure bone mineral density. However, due to its efficient and nonintrusive technique it has recently been recognized as a gold standard technique to evaluate fat and lean mass plus bone mineral content for total body as well as regional body composition (Ackland et al., 2012). A DEXA scanner (General Electric, Prodigy Pro (Madison, Wisconsin, USA)) was utilized for all body composition testing. Encore software was utilized to provide an output of body composition for each surfer.

3.1.1.2.3.2. Devices

Several devices were used within this study. The HALO[®] (model HG1, HALO[®] Medical Devices, Australia) device was used to measure thoraco-lumbar movement in the sagittal plane. A standard gravity dependent inclinometer (Universal Inclinometer, model UI01, Performance Attainment Associates, Minnesota, United States) was used for to measure hip, shoulder and thoracic kyphosis ROM. To ensure the gravity dependent inclinometer was set to an accurate zero starting point, a vertical reference was established through the use of a bubble level. This reference point was then used throughout all testing.

A standard medical tape measure was used with a centimetre scale on one side and an inch scale on the other; this was used for the assessment of thoracic mobility in the sagittal plane, lumbar flexion and ankle dorsiflexion.

Isometric shoulder strength was measured using a JTech PowerTrack[™] II Commander Hand Held Dynamometer (HHD) (JTECH Medical, Salt Lake City, UT, USA). The device was used with a flat testing surface. The force produced is displayed on the digital consul and strength was measured in Newtons (N). The device is automatically calibrated when turned on.

3.1.1.2.4. Data Analysis

Data analysis was performed with SPSS version 20.0. Descriptive statistics including means, standard deviations were calculated for each measure. A Shapiro-Wilks test ($p > .05$) (Shapiro & Wilk, 1965) and a visual inspection of their frequency histograms, normal Q-Q plots and box plots showed that the all key variables were approximately normally distributed for both the competitive and recreational groups; with the magnitude of skewness and kurtosis being non-significant (Barnes, 1998; Cramer, 2012). For comparative analysis independent t - tests were used to determine significant differences between groups. Paired t - tests were used to compare side to side differences within groups. For categorical data, a Chi square test of independence was used.

3.1.1.2.5. Design

All subjects underwent an analysis of body composition through DEXA and a comprehensive series of ROM and strength tests. Six regions of the body were assessed for range of motion; this included the cervical, thoracic and lumbar spine, shoulders, hips and ankles. Two regions were assessed for muscle strength and endurance; this included the shoulder and the trunk region. Testing was completed within an hour. Subjects with a current injury were excluded from testing until the injury had fully resolved (for at least a period of 3 months). Only surfers who were uninjured and unrestricted in surfing activities at the time of testing were included in the data analysis.

Prior to all testing procedures, a standardised explanation and illustration was given regarding the correct movement, position and purpose of test. Subjects were then instructed to practice the required movement. Once the subject could perform the movement correctly, two measurements were recorded. The average of both measurements was used for analysis. All testing procedures are summarised in Appendix 3. Each test was chosen based on the accessibility of clinical equipment, supporting literature in terms of reliability and validity and whether the test position used would be appropriate for a surfing population. The rationale for the selection of individual tests is presented in Chapter 2 (see page 112, Table 17). The prone shoulder and thoracic mobility assessment methods were new tests designed

specifically for a surfing cohort. Both methods were thoroughly investigated in Chapter 2 (sections 2.6.1. and 2.6.2.) and were determined to be highly reliable.

3.1.1.3. Results

3.1.1.3.1. Reliability Analysis

As the musculoskeletal screen involved 14 range of motion tests and five strength tests; conducting comprehensive reliability studies on each of these was not feasible for the timeframe allowed. Therefore a very small pilot study ($n = 7$) was conducted to determine intra-rater reliability where each subject was measured three times. This was considered appropriate, as reliability of the selected tests had previously been investigated. All intra-class correlation coefficient (ICC) values were within the excellent range ($> .75$) (Lexell & Downham, 2005). The results from the reliability analysis can be found in Appendix 5. As DEXA is considered the gold standard for body composition a small pilot study ($n = 8$) was conducted to ensure high reliability was present. This was part of a larger study which has not been included in this thesis but the candidate was a co-author (Climstein et al., 2015). All ICC scores were in the excellent range ($> .75$).

3.1.1.3.2. Demographics

Key demographic information and a comparison for both competitive and recreational groups are summarised in Table 30. Competitive surfers performed significantly ($p < 0.001$) more hours per week surfing and involved in dry land training.

3.1.1.3.3. Body Composition

Total lean muscle mass and body fat percentages for both competitive and recreational groups are presented in Table 30. Symmetry of body composition for arms and legs is presented in Table 31.

Table 30: Key Demographics and Physical Attributes for Competitive and Recreational Surfers

	Competitive; $n = 23$ (♂; $n = 16$), (♀; $n = 7$)	Recreational; $n = 19$ (♂)	p value
Age (years)	♂ = 26.06 ± 4.72	♂ = 27.56 ± 4.43	$p = .34$
	♀ = 22.14 ± 3.80	-	-
Weight (kg)	♂ = 78.49 ± 6.60	♂ = 75.52 ± 9.22	$p = .29$
	♀ = 65.49 ± 9.10	-	-
Height (cm)	♂ = 180.60 ± 3.45	♂ = 176 ± 7.49	$p = .07$
	♀ = 166.50 ± 6.40	-	-
Surfing experience (years)	♂ = 17.88 ± 5.55	♂ = 14.97 ± 5.60	$p = 0.14$
	♀ = 12.43 ± 3.00	-	-
Total surfing frequency (hours per week)	♂ = 13.31 ± 4.46	♂ = 5.29 ± 2.61	$p < 0.001^*$
	♀ = 12.00 ± 5.00	-	-
Total dry land training (hours per week)	♂ = 4.28 ± 2.24	♂ = 0.68 ± 1.16	$p < 0.001^*$
	♀ = 6.07 ± 8.39	-	-
Total body fat (%) †	♂ = 17.35 ± 2.89	♂ = 18.98 ± 3.30	$p = 0.15$
	♀ = 26.18 ± 4.66	-	-
Total lean muscle mass (kg) †	♂ = 61.57 ± 4.16	♂ = 58.65 ± 6.88	$p = 0.14$
	♀ = 47.44 ± 4.35	-	-
Trunk lean muscle mass (kg) †	♂ = 29.42 ± 2.18	♂ = 27.82 ± 3.13	$p = 0.09$
	♀ = 23.33 ± 2.38	-	-

All values are presented as means and standard deviation ($M \pm SD$), ♂ refers to male; ♀ refers to female; * refers to statistical significance ($p \leq .05$) between competitive and recreational surfers; † refers to sample size change (Competitive; $n = 20$, (♂, $n = 14$), (♀, $n = 6$)).

Table 31: Symmetry of Lean Muscle Mass for Competitive and Recreational Surfers

Competitive; $n = 20$ (♂, $n = 14$), (♀, $n = 6$) Recreational; $n = 19$	Dominant arm (kg)	Non-dominant arm (kg)	p value
Competitive (♂)	4.38 ± 0.52	4.38 ± 0.46	$p = .91$
Competitive (♀)	2.84 ± 0.21	2.75 ± 0.32	$p = .52$
Recreational (♂)	4.25 ± 0.64	4.17 ± 0.70	$p = .29$
	Front leg	Back leg	
Competitive (♂)	9.94 ± 0.89	9.98 ± 0.86	$p = .67$
Competitive (♀)	7.77 ± 0.85	7.64 ± 0.78	$p = .09$
Recreational (♂)	9.45 ± 1.20	9.50 ± 1.24	$p = .60$

All values are presented as means and standard deviation ($M \pm SD$), ♂ refers to male; ♀ refers to female.

3.1.1.3.4. ROM Assessment

All ROM values for each individual test has been presented in Table 32. Means and standard deviations are presented for each group along with a comparative analysis between male competitive and recreational surfers. A comparison between sides of all upper and lower limb movements was conducted on the entire cohort. Paired t -tests revealed recreational surfers had significantly ($p = .02$; $t = -2.49$) less IR in the dominant arm compared to the non-dominant arm ($M = 45.92$, $SD = 7.97$ vs. $M = 49.42$, $SD = 9.07$ degrees). All other comparisons between sides for upper and lower limb movements for both competitive and recreational surfers were non-significant ($p > .05$).

Table 32: Range of Motion Values for Competitive and Recreational Surfers

	Competitive; $n = 23$ (♂; $n = 16$), (♀; $n = 7$)	Recreational; $n = 19$ (♂)	p value	Overall M (♂)
Cervical flexion (degrees)	♂ = 68.44 ± 8.29	♂ = 64.26 ± 9.87	$P = 0.19$	♂ = 66.17 ± 9.29
	♀ = 64.57 ± 8.12	-	-	-
Cervical extension (degrees)	♂ = 83.41 ± 6.44	♂ = 79.84 ± 8.75	$P = 0.19$	♂ = 81.47 ± 7.88
	♀ = 89.42 ± 7.76	-	-	-
Cervical rotation† (degrees)	♂ = 72.03 ± 5.29	♂ = 71.33 ± 7.12	$P = 0.77$	♂ = 71.65 ± 6.27
	♀ = 75.36 ± 4.71	-	-	-
Thoracic kyphosis	♂ = 30.66 ± 8.76	♂ = 31.18 ± 7.67	$P = 0.85$	♂ = 30.94 ± 8.06
	♀ = 22.86 ± 3.67	-	-	-
Thoracic extension (tape measure; cm)	♂ = 9.91 ± 1.23	♂ = 9.37 ± 1.15	$P = 0.18$	♂ = 9.62 ± 1.20
	♀ = 9.81 ± 1.19	-	-	-
Thoracic extension (HALO; degrees)	♂ = 82.38 ± 16.41	♂ = 85.45 ± 13.65	$P = 0.55$	♂ = 84.04 ± 14.83
	♀ = 90.78 ± 28.49	-	-	-
Thoracic rotation† (degrees)	♂ = 63.55 ± 7.83	55.66 ± 8.92	$P = 0.01^*$	♂ = 59.26 ± 9.22
	♀ = 60.17 ± 6.48	-	-	-
Lumbar flexion (cm)	♂ = 22.13 ± 0.89	♂ = 21.69 ± 1.20	$P = 0.16$	♂ = 21.85 ± 1.09
	♀ = 21.24 ± 0.77	-	-	-

	Competitive; $n = 23$ (♂; $n = 16$), (♀; $n = 7$)	Recreational; $n = 19$ (♂)	p value	Overall M (♂)
Lumbar extension (cm)	♂ = 37.42 ± 3.73	♂ = 33.07 ± 5.96	$P = 0.01^*$	♂ = 35.06 ± 5.46
	♀ = 38.04 ± 3.50	-	-	-
Hip IR† (degrees)	♂ = 30.06 ± 7.86	24.16 ± 7.86	$P = 0.03^*$	♂ = 26.86 ± 8.30
	♀ = 28.32 ± 5.37	-	-	-
Hip ER† (degrees)	♂ = 39.92 ± 7.13	41.25 ± 5.71	$P = 0.55$	♂ = 40.64 ± 6.33
	♀ = 38.57 ± 9.03	-	-	-
DF† (cm)	♂ = 17.14 ± 2.68	♂ = 12.63 ± 2.34	$P < 0.001^*$	♂ = 14.69 ± 3.36
	♀ = 13.25 ± 1.59	-	-	-
Shoulder IR in prone† (degrees)	♂ = 51.48 ± 7.22	♂ = 47.67 ± 7.97	$P = 0.15$	♂ = 49.41 ± 7.77
	♀ = 48.93 ± 13.91	-	-	-
Shoulder ER in prone† (degrees)	♂ = 95.73 ± 8.73	♂ = 92.97 ± 6.93	$P = 0.30$	♂ = 94.24 ± 7.81
	♀ = 91.43 ± 10.04	-	-	-
Shoulder flexion† (degrees)	♂ = 179.31 ± 6.46	♂ = 178.62 ± 7.70	$P = 0.77$	♂ = 178.94 ± 7.07
	♀ = 177.00 ± 9.95	-	-	-

All values are presented as means and standard deviation ($M \pm SD$), ♂ refers to male; ♀ refers to female; † refers to averages determined with right and left values; * refers to statistical significance ($p \leq .05$).

3.1.1.3.5. Strength Assessment

3.1.1.3.5.1. Shoulder and Trunk Isometric Strength Testing

Comparative analysis was conducted to determine if differences existed between dominant and non-dominant arms for competitive and recreational surfers. Internal rotation strength was significantly ($M = 20.92$ vs. 18.69 , $t = -3.18$; $p < .001$) higher in the dominant arm compared to the non-dominant arm for recreational surfers only (see Table 3). The internal rotation strength was also significantly greater than external rotation strength regardless of competitive status or gender for dominant ($t = 14.98$; $p < .001$) and non-dominant arms ($t = 14.21$; $p < .001$). Table 34 presents descriptive data for hold times for isometric trunk tests. No significant differences were identified between competitive and recreational surfers.

3.1.1.3.5.2. Single Knee Bend

A total of 22 surfers had some form of movement dysfunction in their back leg and 29 had an abnormal movement pattern in their front leg during the single knee bend test. No significant difference ($p > .05$) was found in the total number of movement dysfunctions between the competitive and recreational cohorts and therefore data was pooled together for this variable.

To determine which segment (trunk, pelvis, knee and foot) was primarily contributing to these abnormal movement patterns, a Chi square test of independence was used. There was a significantly higher frequency of abnormal movement patterns reported for the knee region for both the front leg ($n = 17$, $\chi^2 = 21.63$, $p < .01$) and back leg ($n = 11$, $\chi^2 = 9.90$, $p < .05$). Figure 27 illustrates the frequency of abnormal movement patterns at each segment during the single knee bend test.

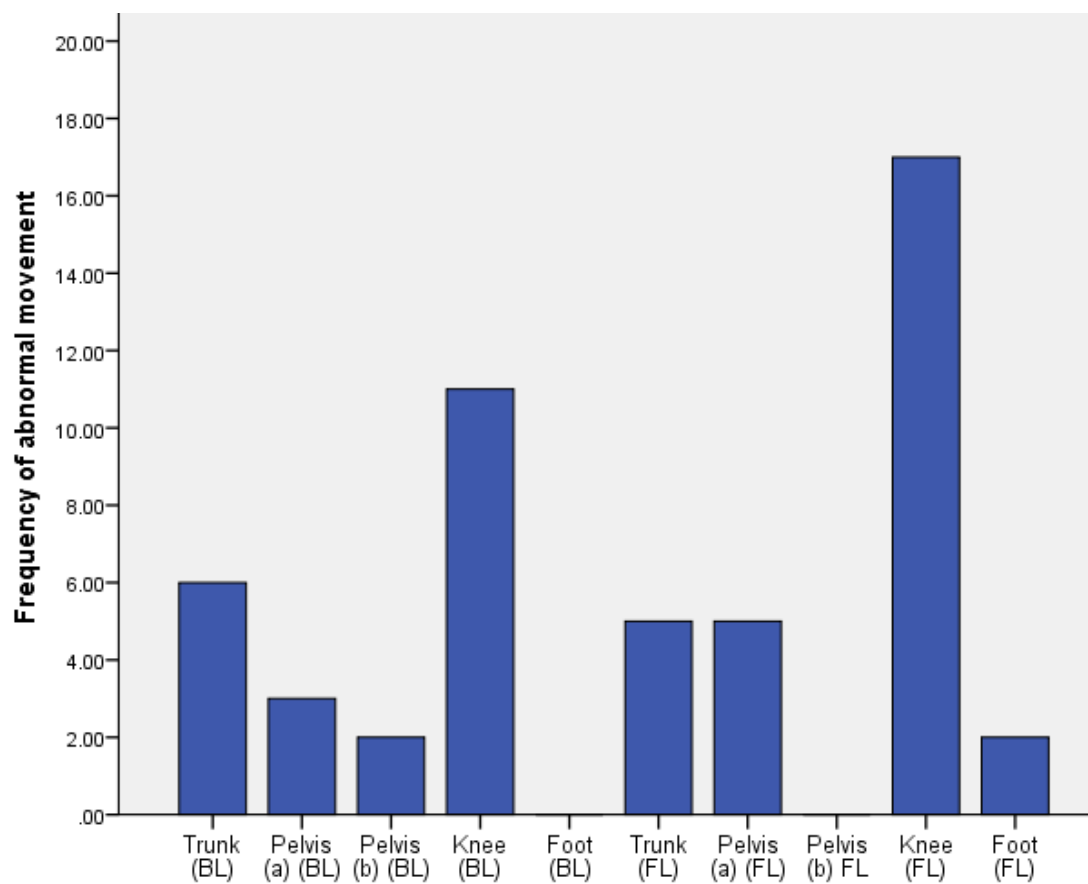


Figure 27: Frequency of Abnormal Movement Patterns during the Single Knee Bend Test

Abbreviations: BL refers to back leg; FL refers to front leg; Trunk refers to movement out of neutral in the frontal plane, Pelvis (a) refers to movement out of neutral in the frontal plane; Pelvis (b) refers to movement away from the midline; Knee refers to patella movement out of line with 2nd toe; Foot refers to movement into pronation.

Table 33: Isometric Shoulder Strength for Dominant and Non-Dominant Arms for Competitive and Recreational Surfers

Competitive; $n = 23$ (♂, $n = 16$), (♀, $n = 7$) Recreational; $n = 19$	Dominant arm			Non-dominant arm		
	ER	IR	ER:IR	ER	IR	ER:IR
Competitive (♂)	8.90 ± 3.41	21.52 ± 5.05	42.81 ± 13.41	8.32 ± 3.41	20.17 ± 5.03	41.56 ± 3.35
Competitive (♀)	8.69 ± 5.17	20.08 ± 11.21	43.81 ± 10.84	8.56 ± 5.17	19.43 ± 12.31	45.77 ± 11.12
Recreational (♂)	8.58 ± 2.10	$20.92 \pm 5.08^*$	45.30 ± 14.86	8.18 ± 2.28	$18.69 \pm 4.18^*$	42.08 ± 13.56

All strength values are percentages of body mass and are presented as the mean and standard deviation ($M \pm SD$); *Indicates significant difference between dominant and non-dominant arms; ER:IR refers to external to internal strength ratio; ♂ refers to male; ♀ refers to female.

Table 34: Isometric Trunk Endurance Times for Competitive and Recreational Surfers

	Competitive; $n = 23$ (♂; $n = 15$), (♀; $n = 7$)	Recreational; $n = 19$ (♂)	p value	Overall M
Beiring Sorenson (s)	♂ = 160.13 ± 40.47	♂ = 136.89 ± 37.44	$p = .09$	♂ = 147.15 ± 39.96
	♀ = 170.67 ± 83.64	-	-	-
Right side hold (s)	♂ = 128.40 ± 40.67	♂ = 108.53 ± 30.06	$p = .12$	♂ = 117.84 ± 36.26
	♀ = 116.00 ± 50.00	-	-	
Left side hold (s)	♂ = 130.93 ± 50.76	♂ = 115.00 ± 30.69	$p = .29$	♂ = 122.47 ± 41.41
	♀ = 121.29 ± 54.21	-	-	

All values are reported as the mean and standard deviation ($M \pm SD$), ♂ refers to male; ♀ refers to female

3.1.1.4. Discussion

The purpose of this study was to implement the musculoskeletal portion of a surf specific screen on both competitive and recreational surfers and subsequently provide a musculoskeletal profile. This has effectively been done with the results from strength, ROM and DEXA testing discussed below.

3.1.1.4.1. Isometric Strength Tests

3.1.1.4.1.1. Shoulder Isometric Tests

A major activity requirement for surfing is paddling and therefore strength assessment in the shoulder region was justified. The high frequency of acute (Furness et al., 2015) and chronic (Furness et al., 2014) shoulder injuries further instigated assessment in this region. Isometric assessment of external and internal rotators was assessed using a HHD. Adequate muscle balance between agonist and antagonist muscles is thought to provide stabilization to the naturally unstable shoulder joint (Hurd et al., 2011). An imbalance between shoulder ER and IR strength has been previously associated with shoulder pathology, such as impingement, tendinopathy or instability (Costill et al., 1991).

This study used a prone and supine position with the HHD fixed to the ground to assess ER and IR. Initially an analysis was undertaken which revealed no differences between arm dominance for competitive surfers. However, internal rotation strength was significantly higher in the dominant arm compared with the non-dominant arm for the recreational surfer (see Table 34). This finding may be due to recreational surfers still developing paddling skills compared with the competitive surfer who may have refined paddling mechanics. Asymmetry between arm dominance has been shown in high school swimmers (Ramsi, Swanik, Swanik, Straub, & Mattacola, 2004); whereas symmetry has been shown in competitive swimmers (Beach, Whitney, & Dickoff-Hoffman, 1992; McMaster, Long, & Caiozzo, 1992). Competitive male surfers also took part in significantly ($p < .001$) more dry land training ($M = 4.28$, $SD = 2.24$ vs. $M = 0.68$, $SD = 1.16$ hrs) compared to male recreational surfers. Asymmetry may have been corrected as part of the dry land training in the competitive group.

Baseline values for IR were significantly ($p < .001$) higher than ER values irrespective of competitive status or gender ($M = 21.01$, $SD = 6.27$ vs. $M = 8.72$, $SD = 2.82$). This finding is in agreement with previous swimming specific studies (Beach et al., 1992; McMaster et al., 1992). Swimming studies quantified muscle activity during a stroke and found that the concentric action of the internal rotators during the propulsive aspect of paddling accounts for 70% of the entire stroke (Richardson, Jobe, & Collins, 1980). Quantifying muscle activity has not been determined with paddling, however due to the similarities in technique it could be hypothesised that the concentric action of the internal rotators would be similar to swimming. The reliance on the internal rotators to produce forward movement coupled with high repetition may result in strength adaptations in the internal rotators.

The role of the external rotators has also been quantified in the sport of swimming; here the external rotators work eccentrically to decelerate the humerus during the propulsive phase of the swim stroke. Once again, muscle recruitment has not been quantified during paddling and therefore it can only be assumed that the external rotators have a similar role as they have during swimming. It has been proposed that high eccentric demands placed on the external rotators may cause chronic fatigue, making it difficult to control glenohumeral joint translation and ultimately predisposing the shoulder to injury (Weldon & Richardson, 2001).

This study found the ratio of ER:IR to range from 42% to 46% for the entire cohort. Surprisingly this is lower than previous research investigating ER:IR ratios. Although there appear to be discrepancies with regards to the ideal ratio, previous swimming and overhead athlete studies have found higher ratios ranging from 66 to 75% (Beach et al., 1992); with some studies producing ratios closer to 100% (Hurd et al., 2011; Ramsi et al., 2004). A possible explanation for the lower ratios in this current study may be attributed to the testing position. In the current study ER strength was assessed in supine with the external rotators in a shortened position. IR strength however, was assessed in prone with the internal rotators in more of a lengthened position. It may be hypothesised that the prone position favoured the contraction of the internal rotators. Ideally, a mid-range position of glenohumeral rotation should have been chosen as this takes advantage of the force length principle. Here maximal force production is possible when optimal actin and myosin overlap is present (Hurd et al., 2011).

Two studies (Hurd et al., 2011; Ramsi et al., 2004) assessed isometric strength of the internal and external rotators using a mid-range position of the humerus and revealed higher ER:IR ratios compared to the current study. Both studies conducted isometric testing by allowing the tester to manually hold the device against the subjects forearm. This position may allow an optimal contraction for both muscle groups. However, the ability to provide a reliable resistance when the subject pushes into the dynamometer is questionable. Hence, the ground was chosen for the current study in order to provide a reliable resistance to the subject when pushing into the device.

Future studies should look to utilize a mid-range position of glenohumeral rotation to limit any bias towards one muscle group and optimize force production. The assessment of ER and IR strength prior, during and following surfing of various durations may identify thresholds of fatigue for either muscle group. Knowing this information may provide direction towards preventing overuse injuries. In addition, if one muscle group were fatiguing before another, this would provide rationale for endurance exercises in that particular muscle group.

3.1.1.4.1.2. Isometric Trunk Tests

Establishing an understanding of trunk endurance was essential in providing part of the musculoskeletal profile for both a competitive and recreational surfer. The trunk is commonly stressed during paddling and actual wave riding. While paddling the trunk muscles are utilized to keep the body balanced on the surfboard. During actual wave riding, explosive trunk movements occur to manoeuvre the board. The lumbar region was identified as a prone area for chronic injuries (Furness et al., 2014). Due to the activity requirements and high prevalence of chronic lumbar injuries assessing trunk endurance was justified. Further, isometric endurance tests for the trunk have been linked to previous history of back pain and are used to predict future back pain.

Due to the rotational demands of surfing, side bridging on both the left and right side were assessed. Beiring Sorenson which assesses extension endurance was assessed due to the extension demands while paddling. Both competitive and recreational male presented excellent endurance scores when compared to other normative data (McGill et al., 2010). Interestingly no statistical difference existed between both competitive and recreational males for any of the tests.

From a clinical point of view all scores for the competitive cohort were all at least 10% greater than the recreational group. When comparing these results (see Table 34) to sedentary people, the surfing cohorts appear to have greater hold times. This is evident in a study by McGill et al. (2010) who assessed 181 university students; the average hold time for Beiring Sorenson was 141 seconds for males and 155 seconds for females. For left and right side bridge, the average hold time was 96 and 97 seconds respectively for men and 68 and 69 respectively for women. When comparing the current study results to water based athletes such as stand up paddle boarders they appear similar (Schram, Hing, Climstein, & Walsh, 2014). These results indicate that the activity requirement of surfing may potentially develop the trunk musculature. Surfers with current back pathologies need to be assessed to determine baseline values for this cohort. Ideally, prospective studies need to be undertaken, which are longitudinal in nature to determine surfers who are at risk of developing lumbar pathologies.

3.1.1.4.2. Functional Assessment

3.1.1.4.2.1. Single Knee Bend Test

The single knee bend test was assessed using a segmental and overall assessment method (using a dichotomous scale of yes or no for acceptable movement). Approximately 50% of surfers had some form of movement abnormality; with the knee having a significantly ($p < .05$) higher frequency than any other region. This information provides rationale for the inclusion of knee strength and stability exercises in a surfing cohort. During rehabilitation and or strength and conditioning exercises, particular emphasis and assessment should be directed at the knee region.

3.1.1.4.3. ROM Assessment

The assessment of ROM in a surfing cohort was crucial to identify baseline levels, determine if asymmetries were present between upper and lower limbs and finally to make comparisons between competitive and recreational groups.

3.1.1.4.3.1. Cervical Spine

Cervical ROM was assessed in both the sagittal and horizontal planes; extension values ranged from 64.3 to 68.4 degrees and flexion values ranged from 79.8 to 89.4 degrees irrespective of competitive status or gender. The apparent difference in cervical extension could be due to the activity requirements of surfing. During recreational and competitive surfing the majority (> 50%) of time is spent paddling in a prone position, (Farley et al., 2012b; Secomb et al., 2015) where the cervical spine must remain in an extended position. It could be postulated that the constant activity requirement of extension results in adaptive joint ROM increases in extension shortening of cervical extensor thus limiting the amount of cervical flexion. In comparison to previous research assessing cervical ROM using a CROM device extension the current study values appear higher (Audette et al., 2010; Fletcher & Bandy, 2008). Fletcher and Bandy (2008) who assessed healthy individuals (mean age of 26 years) reported an average of 52.9 and 78.8 degrees for cervical flexion and extension respectively.

3.1.1.4.3.2. Thoracic Spine

The thoracic spine was also assessed statically in the sagittal plane and dynamically in the sagittal and coronal planes. This study revealed thoracic kyphosis values ranging from 22.9 to 30.9 degrees regardless of competitive status or gender. These values are consistently lower when compared to similar age matched individuals. O'Gorman and Jull (1987) used the same method as the current study and found that for the age range of 22 to 29 years the average thoracic kyphosis was 40.7 degrees for females. Lewis and Valentine (2010) also reviewed thoracic kyphosis in males and females with a mean age of 32 years and found a combined average of 35.5 degrees. Once again, adaptive changes due to the requirement of paddling may provide some rationale as to why surfers reveal lower kyphosis values.

Thoracic rotation was also consistently higher in this surfing cohort ($M = 55.6$ to 63.6 degrees) compared to previous research. Johnson et al. (2012) assessed thoracic rotation in males and females (M age of 23 years) using the same method and found mean thoracic rotation to be 40.8 degrees. Thoracic rotation movement is evident during actual wave riding; here a surfer will rotate towards the wave during the bottom turn and then rotate away from the wave during the top turn. Reduced ROM in this region may potentially hinder the ability to perform such manoeuvres. This may explain why competitive surfers had significantly more thoracic rotation compared to recreational surfers. The significant increase in thoracic rotation in the competitive cohort may be an adaptive response to repetitively completing more radical torsional movements. As previously mentioned they also may be involved in more dry land training which may aid in improving movement in the thoracic region.

3.1.1.4.3.3. Lumbar Spine

Lumbar flexion and extension ROM was assessed in the sagittal plane. Lumbar flexion was measured in a standing position using the modified-modified schober technique (Tousignant et al., 2005). The lumbar flexion values (21.2 to 22.1 cm) appear similar to previous research with non-athletic populations (>19 cm) (Mayer, Chen, Lavender, Trafimow, & Andersson, 1995) and greater than research using subjects with low back pain (Williams, Binkley, Bloch, Goldsmith, & Minuk, 1993).

The measurement of lumbar extension was conducted in a prone position that is specific to a surfing population and commonly a requirement prior to standing up on a surfboard or during a duck dive (pushing the board under the water). Lumbar extension values ranged from 33.1 to 38.0 cm using a method outlined by Bandy and Reese (2004). These values appear higher than previous research conducted on 63 males and females (M age of 26 years) where the mean amount of lumbar extension was 32.4 cm (Bandy & Reese, 2004). Once again, the constant activity requirement of paddling involves lumbar extension and may result in adaptive joint ROM increases in extension and shortening of lumbar extensors thus limiting the amount of lumbar flexion.

Significantly ($p < .001$) greater lumbar extension was found in competitive surfers compared to recreational surfers. Competitive surfers spend significantly ($p < .001$) more hours per week surfing (13.3 vs. 5.3 hrs.) and complete significantly ($p < .001$)

more dry land training (4.3 vs. 0.7 hrs.). This may assist in promoting these adaptations in a competitive cohort.

3.1.1.4.3.4. Hip

Both hip ER and IR rotation were measured bilaterally in a sitting position as this was considered to be the most specific testing position for a surfing population. This study has provided baseline values for both ER (38.6 to 41.3 degrees) and IR (24.2 to 30.1 degrees) in competitive and recreational cohorts. The values for ER appear to be consistent with previous research utilizing a sitting position (Simoneau et al., 1998). In the current study ER is consistently greater than IR; this is commonly the case in other studies assessing hip ROM regardless of position (Malliaras, Hogan, Nawrocki, Crossley, & Schache, 2009; Simoneau et al., 1998).

The values for IR for both surfing cohorts appear lower than previous research utilizing a sitting position (Simoneau et al., 1998). It could be hypothesised that limitations in hip IR ROM restriction could be attributed to capsular tightness (Verrall et al., 2005). Multiple turning and twisting demands can lead to stress and/ or inflammatory/ repair response to the hip capsule and surrounding ligaments (Verrall et al., 2005). These types of movements are commonly occurring during actual wave riding. Clinicians should try to screen/monitor hip ROM in surfing populations and where restriction is evident, appropriate treatment interventions should be implemented.

Symmetry with ROM was identified between the front and back leg. The terms front or back leg was chosen as a surfer will either stand with the left leg forward (regular stance) or the right leg forward (goofy stance); therefore, one leg is forward and one is back. It was hypothesised that greater stresses are placed on the back leg and potentially ROM differences may exist compared to the front leg. However, this was not the case as paired *t* tests revealed no significant differences for either IR or ER in the front and back leg in either cohort.

Competitive surfers had significantly ($p = .03$) greater IR compared to recreational surfers (30.1 vs. 24.2 degrees). Through video graphic evidence the more difficult manoeuvres require excessive IR at the hip joint (Everline, 2007). It could be postulated that as competitive surfers can perform such manoeuvres it results in

adaptations in hip IR ROM. Additionally, competitive surfers are involved in more land based training which may include stretching around the hip region.

3.1.1.4.3.5. Ankle

Ankle DF ROM was assessed using a knee to wall test (Bennell et al., 1998). Baseline values have been provided for ankle DF for both competitive and recreational cohorts. The values of the current study (12.6 to 17.1 cm) appear consistently higher compared to non-athletic populations which range from 9.5 to 13.6 cm in age groups of 18 to 24 years (Bennell et al., 1998; Konor, Morton, Eckerson, & Grindstaff, 2012). Symmetry was identified between the front and the back leg, irrespective of competitive status or gender. Competitive surfers had significantly greater DF compared to the recreational counterparts. As previously described, video graphic evidence suggests that manoeuvres performed in surfing require excessive ankle DF. Therefore, this may be an adaptation or possibly a result of competitive surfers taking part in ankle stretching.

3.1.1.4.3.6. Shoulder

The shoulder joint was assessed for the movements of flexion, IR and ER. Both IR and ER were assessed in a prone position; to our knowledge only one study exists which has assessed ER in a prone position (found in Chapter 2, section 2.6.2.). The baseline values recorded in this study for shoulder flexion (177.0 to 179.3 degrees) and IR (47.7 to 51.5 degrees) appear greater than previous research investigating non-athletic populations (Kolber & Hanney, 2012; Muir et al., 2010). For ER the surfing population values (91.4 to 95.7 degrees) are higher than values of the non-athletic population (89.7 degrees) described in Chapter 2, section 2.6.2. It could be hypothesised that the prone position favours a surfing population due to the requirements of paddling.

Interestingly this was the only region where asymmetry between the non-dominant and dominant arm was detected. Recreational surfers had significantly ($p \leq .05$) less IR in the dominant arm compared to the non-dominant arm. This finding is interesting given the fact that recreational surfers also had significantly greater IR strength on the

dominant arm. The increase in strength may be associated with reduced ROM in the dominant arm. Previous research supports this theory as a reduction in range of motion/flexibility has followed isolated strength training (Kubo, Kanehisa, Ito, & Fukunaga, 2001). Screening measures should be implemented to address asymmetries in conjunction with general conditioning exercises to maintain adequate ROM.

3.1.1.5. Conclusion

This study has presented an extensive musculoskeletal profile of both competitive and recreational surfing cohorts. Several discrepancies are apparent between both cohorts and when comparing the current study's findings with previous research. This information provides a reference for ROM and strength values for both recreational and competitive cohorts and should be used by clinicians, coaches and trainers who are dealing with surfing populations. It could be used to assist with rehabilitative goals and/or direct conditioning exercises, prevent injuries and potentially enhance performance. Ideally, longitudinal studies are needed to determine which tests may be predictors of future injuries.

3.1.2. PHYSIOLOGICAL PROFILE OF RECREATIONAL AND COMPETITIVE SURFERS

Furness, J., Hing, W., Newcomer, S., Sheppard, J. M., & Climstein, M. The physiological profile of competitive and recreational surfers (journal yet to be determined).

3.1.2.1. Abstract

Background: Surfing comprises of both high and low intensity paddling utilising both the aerobic and anaerobic systems. Existing physiological studies lack adequate group sample sizes and female surfers; vary in VO_{2peak} and power output values and are yet to determine differences between competitive and recreational surfers. *Aim:* To provide a comprehensive physiological profile of both recreational and competitive surfers. *Methods:* This was a multi-site study that involved 72 surfers, recreational ($n = 52$) and competitive ($n = 20$). Anthropometric measurements were conducted followed by DEXA, anaerobic testing and finally aerobic testing. *Results:* VO_{2peak} was significantly greater in both male ($M = 40.71$ vs. 31.25 ml/kg/min, $p < .001$) and female ($M = 34.31$ vs. 24.61 ml/kg/min, $p < .001$) competitive cohorts compared to recreational surfers. This was also paralleled for anaerobic power ($M = 303.93$ vs. 264.58 W) for competitive male surfers. Arm span and lean total muscle mass was significantly ($p \leq .01$) correlated with key performance variables (VO_{2peak} and anaerobic power). No significant ($p \geq .05$) correlations were revealed between season rank and each of the variables of interest (VO_{2peak} and anaerobic power). *Conclusion:* Key performance variables (VO_{2peak} and anaerobic power) are significantly higher in competitive surfers indicating this is both an adaptation and requirement in this cohort. Interestingly no significant correlation was identified between key performance variables and ranking in the competitive cohort. This suggests tests that replicate wave-riding components, may be more appropriate to discriminate in the level of performance. This comprehensive study adds to the physiological profile of a recreational and competitive surfer. This battery of physiological tests could be used as a screening tool to identify an athlete's weaknesses or strengths. Coaches and clinicians could then select appropriate training regimes to address weaknesses and therefore focus less on strengths.

3.1.2.2. Introduction

The basic physiological requirements and skills of surfing has remained unchanged for over a 1,000 years - a surfer paddles a board out to the waves and rides it back to shore (Moser, 2008; O'Rourke, 2006). With time motion analysis, the sport can be further broken down into periods of repetitive upper body movement during paddling and prolonged periods of sitting, interspersed with intermittent explosive lower body and trunk movements (Mendez-Villanueva & Bishop, 2005). Several studies have revealed that paddling is the predominant aspect of surfing and encompasses approximately 50% of a surfing session or competitive heat (Farley et al., 2012b; Meir et al., 1991; Secomb et al., 2015; Watsford, Murphy, & Coutts, 2006). The activity requirements of a 20 minute heat in young competitive surfers using global positioning system (GPS) technology has previously been analysed. Results revealed that 54% of the total time involved paddling with a mean heart rate of 140 ± 11.6 beats/min (Farley et al., 2012b). The majority of these paddling bouts (60%) were only 1 to 20 seconds long; highlighting the importance of short intense paddling. The activity requirements for young recreational surfers revealed similar results with paddling encompassing 42.6 to 44% of the total time and mean heart rates ranging between 128 ± 13 to 135 ± 6.9 beats/min (Meir et al., 1991; Secomb et al., 2015).

It is apparent that both forms of surfing are intermittent in nature, and clearly utilize the aerobic and anaerobic energy systems. It could be suggested that surfers must possess a highly developed capacity to physiologically recover in short rest periods before recommencing high intensity paddling bouts. Aerobic (VO_{2peak}) and anaerobic (peak watts) physiological testing through paddling assessment has previously been assessed in several studies (see Table 38).

Loveless and Minahan (2010a) conducted the only study, which compared competitive and recreational surfers and revealed no significant differences between the groups for VO_{2peak} values. Méndez-Villanueva et al. (2005) also revealed no differences in VO_{2peak} scores when European level surfers were compared against Regional level surfers. Only two studies (Farley et al., 2012a; Loveless & Minahan, 2010a) have assessed peak power output using ergometers; discrepancies in mean peak power out values are evident between studies. Competitive surfers have been shown to possess significantly ($p < .05$) higher peak power outputs (Farley et al., 2012a; Loveless & Minahan, 2010a) and season rank has been significantly ($p < .05$) correlated with peak power output (Farley et al., 2012a).

A key theme in these physiological studies is the variation in $\text{VO}_{2\text{peak}}$ values ($M = 37.8$ to 54.2 ml/kg/min) and peak power outputs ($M = 205$ to 348 W). An explanation for the variations may be due to differences in equipment and testing protocols used. There also appears to be no difference in $\text{VO}_{2\text{peak}}$ scores between recreational and competitive surfers, despite this being a common finding in most mainstream sports. It should be noted that all of these studies investigating $\text{VO}_{2\text{peak}}$ lack adequate group sample sizes ($n < 10$). This limits the ability to reveal differences between groups and generalise results to surfing cohorts. There is also a complete absence of upper body aerobic fitness testing pertaining to female surfers despite female surfing being a professional sport for the past decade.

In conjunction with physiological assessment, several studies have also assessed body composition in both recreational and competitive surfers. Surfers have generally been considered to reveal moderate levels of body fat ranging from 10.5 to 22% (Felder, Burke, Lowdon, Cameron-Smith, & Collier, 1998; Lowdon, 1980; Mendez-Villanueva & Bishop, 2005). Only one study has revealed significant differences between in body composition between surfing cohorts (Sheppard et al., 2013). The interpretation of these results is limited given that body composition was assessed through skinfolds. It has been shown that varying the skinfold site by as little as 1 cm produces significantly different results when experienced practitioners measure the same subject (Ackland et al., 2012). Dual energy x-ray absorptiometry (DEXA) has been shown to be extremely reliable in estimating body composition (Carver, Christou, & Andersen, 2013) and is yet to be used in a surfing population.

It is apparent that further physiological testing is needed in a larger sample size comparing recreational and competitive surfers in both genders. Therefore the aims of this study were; 1) to provide the aerobic and anaerobic profile for competitive and recreational surfers and determine if differences exist between groups; 2) to provide the body composition of competitive and recreational surfing cohorts with the use of DEXA and; 3) to determine if physiological testing could be used in a surf specific screen to assist with discriminating in performance. It is hypothesized that competitive cohorts will have increased anaerobic and aerobic power and decreased body fat compared with recreational surfers.

3.1.2.3. Methods

3.1.2.3.1. Subjects

This was a multi-site study that involved a total of 72 surfers, recreational ($n = 52$) and competitive ($n = 20$). Of the 72 surfers, 62 (86.1%) were males and 10 were females. The 20 competitive surfers were competing on the World Qualifying Series (WQS) or world championship tour (WCT); all remaining surfers were classified as recreational. A total of 39 (54.1%) were tested at Bond University and the remaining 33 were tested at California State University, San Marcos (USA); where only aerobic testing was conducted. Subjects were tested following their normal routine of sleep, nutrition and hydration levels prior to testing. Being a multi-site study ethics was granted through the Bond University Human Research Ethics Committee (RO1610) and through the Institutional Review Board for the Protection of Human Subjects (IRB) at California State University San Marcos (2013-118) prior to commencement.

3.1.2.3.2. Assessors

Testing at Bond University was conducted by a physiotherapist with additional training in exercise testing and an accredited exercise physiologist with over 20 years' experience. Testing at San Marcos was conducted under the direct supervision of an exercise physiologist with over 15 years of experience.

3.1.2.3.3. Design

All subjects tested at Bond University underwent the exact order of testing on the same day. Initially anthropometric measurements were conducted followed by DEXA then anaerobic testing and finally aerobic testing. Testing conducted at San Marcos involved aerobic testing only.

3.1.2.3.3.1 Anthropometrics and Body composition

Anthropometric measurements included height, mass and arm span. Height was initially measured with to the nearest 0.1 cm and body mass was measured with minimal clothing (underwear only) using a standard medical balance scale (Seca, 700, Hamburg, Germany). Arm span was measured to the nearest 0.1 cm according to standard recommendations (Moura et al., 2014). Arm span was divided by height to determine “Ape Index”; a ratio commonly used with sports such as rock climbing and swimming where larger ratios favour the competing athlete (Watts, Joubert, Lish, Mast, & Wilkins, 2003).

A DEXA scanner (General Electric, Prodigy Pro (Madison, Wisconsin, USA)) was utilized for all body composition testing. Encore software provided an output of segmental body composition for each surfer (right & left arms, legs and trunk). All scans were completed according to the standardised DEXA operational protocol (Nana et al., 2014). Surfers were centrally positioned where by both feet were placed on a foam block and foam pads were placed on each hand to help determine tissue differences between arms and trunk (foam is transparent under DEXA). Using a foam block and pads, a constant distance between feet (15cm) and between hands and trunk (3cm) was maintained (Nana et al., 2014). To ensure standardised conditions subjects were required to fast for at least 2 hours prior to testing.

3.1.2.3.3.2. Anaerobic Power Output Testing

Aerobic and anaerobic testing was completed on a wind braked swim bench ergometer (Vasa, Inc., Essex Junction, VT, USA) with the addition of a surfboard mounted on top of the bench. A new display unit with interoperability (ANT+) technology was used to gather all data on the display unit of the swim bench ergometer. This allowed for total peak power, left and right peak power, total distance covered and velocity to be calculated and captured. Total peak power was defined as the highest sample of left plus right watts (W). The resistance unit on the swim bench ergometer provided seven airflow resistance settings. As previous research by Loveless and Minahan (2010b) revealed the maximum power output was achieved at the highest resistance, therefore this setting was applied to the current study.

Anaerobic power output was measured during a 10-second sprint on the swim bench ergometer at maximal effort (completed prior to aerobic testing). The surfer was initially familiarized with the equipment and given standardised instructions on the testing procedures. This was followed by a three-minute warm up at 30 watts and then three 5-second maximal effort sprints with each sprint separated by a 20-second rest period. Following the completion of the warm up the surfer had a 10-minute rest before completing the 10-second sprint at maximal effort. A 10 minute rest period was selected as complete resynthesis of adenosine triphosphate (ATP) occurs within three to five minutes, and complete creatine phosphate resynthesis can occur within eight minutes (Baechle & Earle, 2008; Harris et al., 1976). This protocol was based on previous anaerobic testing conducted on a competitive surfing cohort (Farley et al., 2012a; Loveless & Minahan, 2010b). As previously discussed the inclusion of ANT+ software allows for data on the display unit to be capture and wirelessly transmitted. Peak power, mean power, left and right power outputs, peak velocity and total distance were all calculated.

3.1.2.3.3.2. *Aerobic VO_{2peak} Uptake Testing*

Subjects VO_{2peak} was obtained during an incremental endurance exercise test. Measuring peak oxygen consumption is considered the gold standard for quantifying aerobic fitness. Swim bench ergometry has previously been shown to be both valid and reliable to test peak aerobic and anaerobic levels in recreational and competitive surfers (Farley et al., 2012a; Loveless & Minahan, 2010a). All surfers underwent this test on the swim bench ergometer as described previously. Oxygen consumption was analysed using a Parvo Medics (TrueOne[®], 2400) automated gas analysis system (O_2 analyser, CO_2 analyser, pneumotach). This provided breath-by-breath measurement of oxygen consumption (L/min), and relative to body weight (ml/kg/min), maximal ventilation, and energy expenditure (kcal). Oxygen uptake was averaged every 30 seconds, with the peak value recorded as the highest value obtained over a 30-second period.

The incremental test began at 30 watts, with increments of 10 watts every minute. Testing was terminated if maximum heart rate was exceeded, RER reached greater than 1.5, oxygen consumption did not increase despite an increase in power output, the surfer was unable to maintain the required power output for greater than 10

seconds, volitional exhaustion was achieved or any symptoms of chest pain was expressed by the surfer. This termination criteria was based upon the ACSM guidelines for exercise testing and prescription (Armstrong et al., 2006). The incremental testing protocol was based off previous $\text{VO}_{2\text{peak}}$ testing conducted on a competitive and recreational surfing cohort (Farley et al., 2012a; Loveless & Minahan, 2010a). The testing set up with the surfboard attached to the swim bench is seen in Figure 28.

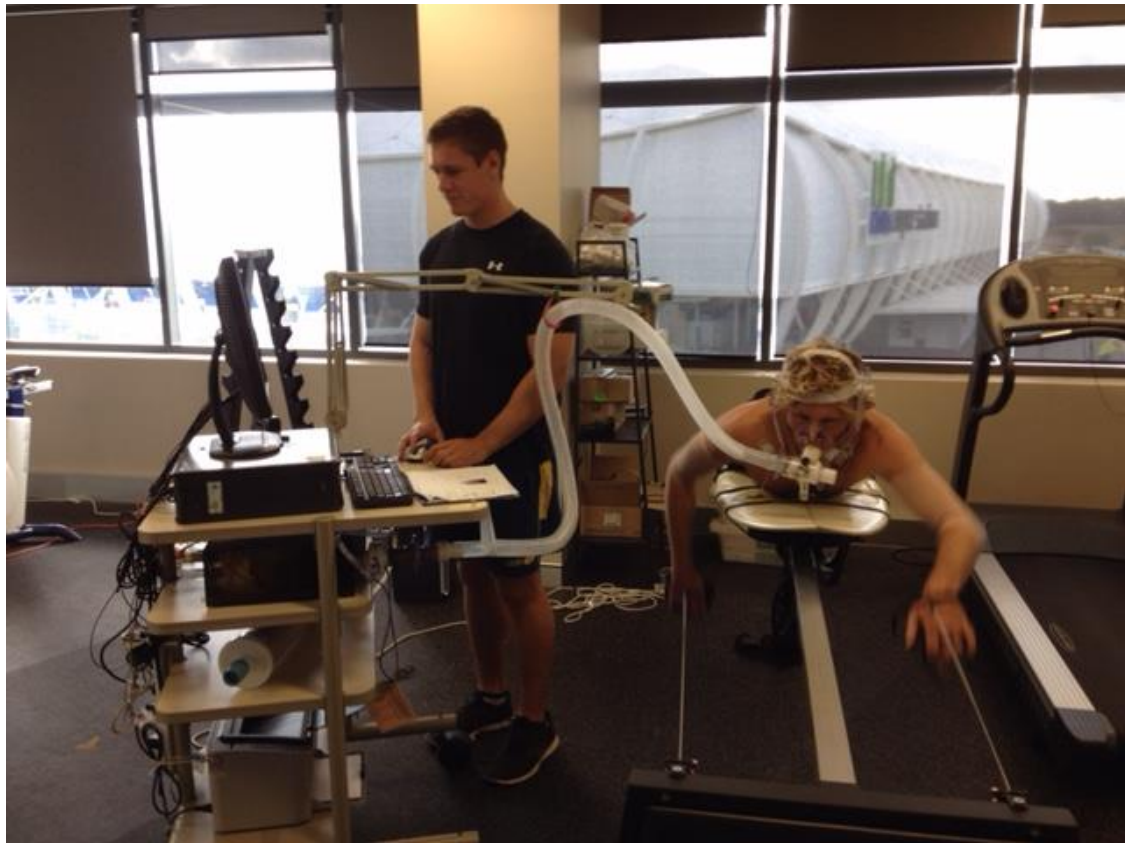


Figure 28: Laboratory Setup of $\text{VO}_{2\text{peak}}$ Testing Performed on the Swim Bench Ergometer

3.1.2.3.4. Data Analysis

Data analysis was performed with SPSS version 20.0. Descriptive statistics including means, standard deviations and ranges were calculated for each measure and for each session. A Shapiro-Wilks test ($p > 0.05$) (Shapiro & Wilk, 1965) and a visual inspection of their frequency histograms, normal Q-Q plots and box plots showed that the all key performance variables (VO_{2peak} , relative anaerobic power and peak anaerobic power) were approximately normally distributed for both the competitive and recreational groups; with the magnitude of skewness and kurtosis being non-significant (Barnes, 1998; Cramer, 2012). For comparative analysis independent t -tests were used to determine significant differences between groups. Paired t -tests were used to determine differences within groups. A Spearman's rank order correlation was conducted between end of year ranking and each of the variables of interest (VO_{2peak} , peak and relative anaerobic power). A Pearson's correlational analysis was conducted with key physical attributes (arm span and total muscle mass) and key performance variables (VO_{2peak} , peak anaerobic power and relative anaerobic power).

Prior to undertaking analysis between the competitive and recreational groups, data collected between both testing sites needed to be analysed to ensure there were no differences in VO_{2peak} , mass and age. Data was only pooled together for the recreational males as this occurred at both testing sites. Female data collected at both sites were used for comparative purposes only (competitive versus recreational). As seen in Table 35, an analysis of key variables was conducted for recreational males tested at both sites. Only aerobic testing was conducted at San Marcos and therefore only key variables that could influence VO_{2peak} scores were analysed. As no significant differences were seen between the two sites for data collection, key descriptive information has been pooled together to provide a recreational group of 47 males.

Table 35: Analysis of Data Collected between Bond University and San Marcos for Recreational Male Surfers

	Bond University (<i>n</i> = 19)*	San Marcos (<i>n</i> = 28)*	<i>p</i> value
Age (years)	27.19 ± 4.24	26.03 ± 5.91	.47
Weight (kg)	74.82 ± 8.66	79.20 ± 11.70	.17
VO _{2peak} (ml/kg/min)	32.75 ± 5.24	30.25 ± 6.85	.19
VO _{2peak} (L/min)	2.45 ± 0.52	2.38 ± 0.55	.64

*Values represent the mean and standard deviation (*M* ± *SD*).

3.1.2.4. Results

3.1.2.4.1. Reliability Analysis

A small pilot study was conducted for both anaerobic (*n* = 7) and DEXA (*n* = 8) assessment. Whereby, each subject was assessed twice on the same day separated by 2 hours. The same assessor completed each assessment in order to evaluate intra-rater reliability. All ICC scores were within the excellent range (> .75).

3.1.2.4.2. Recreational vs. Competitive

A comparative analysis between the competitive and recreational groups for all variables is found in Table 36 and Table 37. Significant differences (*p* < .05) between recreational and competitive groups for key performance variables were identified. Competitive male surfers had significantly greater arm span (*M* = 190.61 vs. 182.61 cm, *p* = .01) compared to male recreational surfers. VO_{2peak} was significantly greater in both male (*M* = 40.71 vs. 31.25 ml/kg/min, *p* < .001) and female (*M* = 34.31 vs. 24.61 ml/kg/min, *p* < .001) competitive cohorts compared to recreational surfers. This was also paralleled for anaerobic power (*M* = 303.93 vs. 264.58 W) for competitive male surfers.

3.1.2.4.3. Physical Attributes and Key Performance Variables

Arm span was significantly ($p \leq .01$) correlated with VO_{2peak} ($r = .55$), relative anaerobic power ($r = .49$) and peak power output ($r = .72$). Total muscle mass was also significantly correlated ($p \leq .05$) with VO_{2peak} ($r = .56$), relative anaerobic power ($r = .49$) and peak power output ($r = .83$). An illustration of height and arm span, VO_{2peak} and anaerobic scores are seen in Figure 29, 30 and 31.

3.1.2.4.4. Season Ranking

A total of 10 competitive male surfers were utilized in the analysis as all of these surfers completed an entire year of competition. Key variables of interest were VO_{2peak} , peak anaerobic power and relative anaerobic power. No significant correlations ($p \geq .05$) were revealed for each of the variables of interest (VO_{2peak} , $r = .33$; peak anaerobic power, $r = .06$; relative anaerobic power, $r = .09$).

3.1.2.4.5. Symmetry in Power Outputs

As power output data was attained during both the anaerobic and aerobic testing, comparisons between dominant and non-dominant arm outputs were conducted using paired t -tests. There was no statistical difference ($p > .05$) between mean dominant and non-dominant arm power outputs for anaerobic (M dominant = 139.14, $SD = 34.30$ vs. M non-dominant = 135.62, $SD = 2.59$ W) and aerobic testing (M dominant = 31.40, $SD = 5.77$ vs. M non-dominant = 31.05, $SD = 5.53$ W) for all surfers.

Table 36: Key Demographics and Physical Attributes for Competitive and Recreational Surfers

	Competitive; $n = 20$ (♂; $n = 15$), (♀; $n = 5$)	Recreational; $n = 52$ (♂; $n = 47$), (♀; $n = 5$)	p value
Age (years)	♂ = 26.73 ± 4.68	♂ = 26.50 ± 5.28	.88
	♀ = 20.6 ± 1.81	♀ = 23.20 ± 0.83	.03*
Mass (kg)	♂ = 77.83 ± 6.62	♂ = 77.42 ± 10.69	.89
	♀ = 68.18 ± 9.57	♀ = 62.86 ± 3.39	.28
Height (cm)	♂ = 179.44 ± 3.96	♂ = 180.13 ± 7.54	.73
	♀ = 169.52 ± 3.04	♀ = 169.40 ± 7.23	.97
Arm span (cm) †	♂ = 190.61 ± 4.79	♂ = 182.61 ± 9.28	.01*
	♀ = 171.70 ± 2.20	♀ = NA	NA
Ape Index†	♂ = 1.06 ± 0.01	♂ = 1.03 ± 0.02	< .001*
	♀ = 1.013 ± 0.02	♀ = NA	NA
Surfing experience (years)	♂ = 18.86 ± 5.46	♂ = 13.22 ± 6.93	.01*
	♀ = 12.40 ± 3.21	♀ = 9.60 ± 5.18	.33
Total surfing frequency (hours per week)	♂ = 13.23 ± 4.54	♂ = 7.56 ± 4.91	< .001*
	♀ = 12.60 ± 5.08	♀ = 8.20 ± 2.86	.13
Total dry land training (hours per week)	♂ = 4.5 ± 2.35	♂ = 2.57 ± 2.93	.02*
	♀ = 6.90 ± 10.10	♀ = 5.60 ± 1.14	.78
Total body fat (%)†	♂ = 17.11 ± 2.93	♂ = 18.86 ± 3.33	.12
	♀ = 26.90 ± 4.82	♀ = NR	NA
Total muscle mass (g) †	♂ = 61.66 ± 4.02	♂ = 58.21 ± 6.46	.81
	♀ = 48.43 ± 4.06	♀ = NA	NA

Vales are presented as the mean and standard deviation ($M \pm SD$); ♂ refers to male; ♀ refers to female; † refers to testing conducted at Bond University only ($n = 39$); * refers to statistical significance ($p \leq .05$); NA refers to “not applicable”.

Table 37: Key Performance Variables for Competitive and Recreational Males and Females

Measure	Competitive; $n = 20$ (♂; $n = 15$), (♀; $n = 5$)	Recreational; $n = 52$ (♂; $n = 47$), (♀; $n = 5$)	p value
Aerobic VO_{2peak} test			
VO_{2peak} (L/min)	♂ = 3.14 ± 0.37	♂ = 2.41 ± 0.53	< .001*
	♀ = 2.37 ± 0.26	♀ = 1.55 ± 0.20	< .001*
VO_{2peak} (ml/kg/min)	♂ = 40.71 ± 3.28	♂ = 31.25 ± 6.31	< .001*
	♀ = 34.31 ± 2.71	♀ = 24.61 ± 2.66	< .001*
Respiratory exchange ratio (RER)	♂ = 1.10 ± 0.07	♂ = 1.21 ± 0.08	< .001*
	♀ = 1.04 ± 0.08	♀ = 1.24 ± 0.11	< .001*
Peak blood lactate (mmol)	♂ = 12.01 ± 3.28	♂ = 12.03 ± 3.37	.99
	♀ = 11.94 ± 1.35	♀ = NA	NA
Peak heart rate (b.min ⁻¹)	♂ = 182.07 ± 5.27	♂ = 175.58 ± 10.51	.03*
	♀ = 184 ± 8.38	♀ = 174.60 ± 11.01	.16
Age predicted heart rate max (%)	♂ = 94.41 ± 4.19	♂ = 90.80 ± 5.53	.03*
	♀ = 92.36 ± 3.67	♀ = 88.71 ± 5.49	.25
Peak aerobic power (W)	♂ = 121.93 ± 9.20	♂ = 101.26 ± 18.49	< .001*
	♀ = 101.80 ± 12.99	♀ = 68.00 ± 16.43	< .001*
Anaerobic 10s test†			
Absolute peak anaerobic power (W)	♂ = 303.93 ± 57.99	♂ = 264.58 ± 46.14	.04*
Mean anaerobic power (W)	♂ = 257.21 ± 47.28	♂ = 224.04 ± 39.75	.03*
Relative anaerobic power (W/kg)	♂ = 3.91 ± 0.63	♂ = 3.53 ± 0.38	.04*
Peak anaerobic speed (m/s)	♂ = 1.65 ± 0.09	♂ = 1.54 ± 0.10	< .001*

Vales are presented as the mean and standard deviation ($M \pm SD$); ♂ refers to male; ♀ refers to female; † refers to testing conducted at Bond University only ($n = 34$); * refers to statistical significance ($p \leq 0.05$); NA refers to “not applicable”.

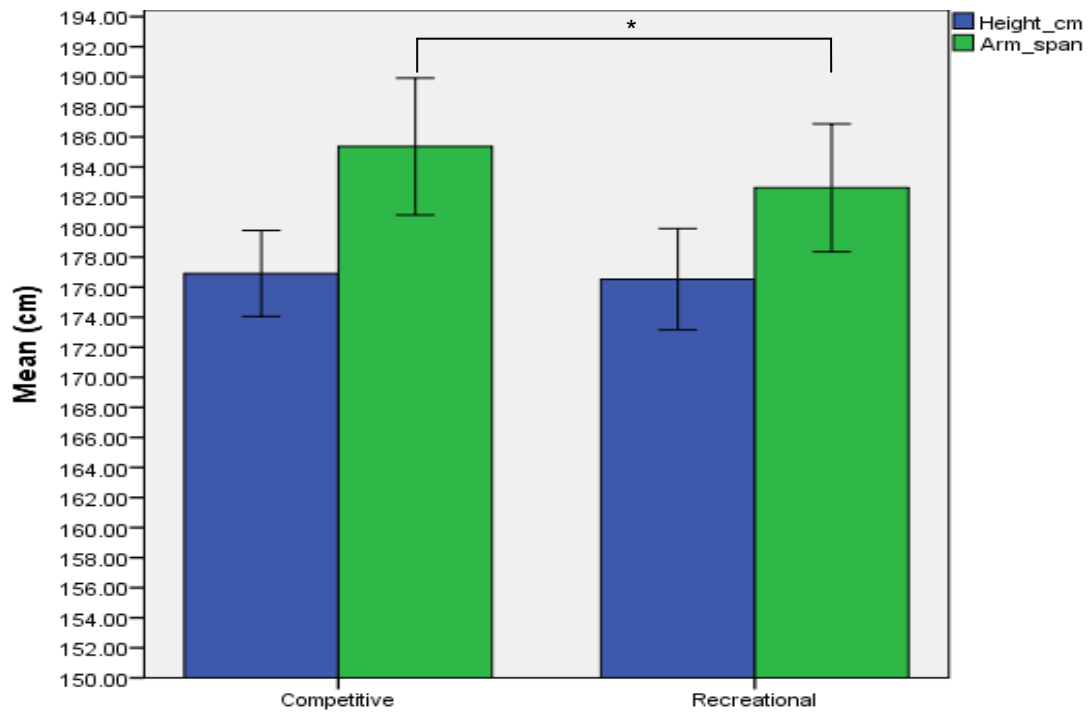


Figure 29: Height and Arm Span for Competitive and Recreational Male Surfers

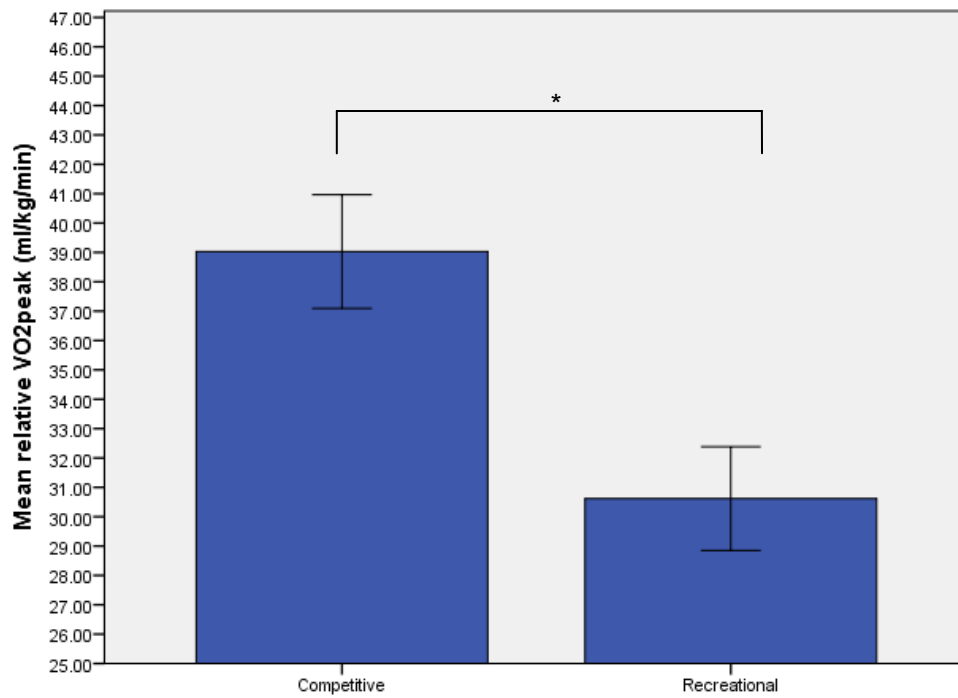


Figure 30: Mean VO_{2peak} Scores for Competitive and Recreational Male Surfers

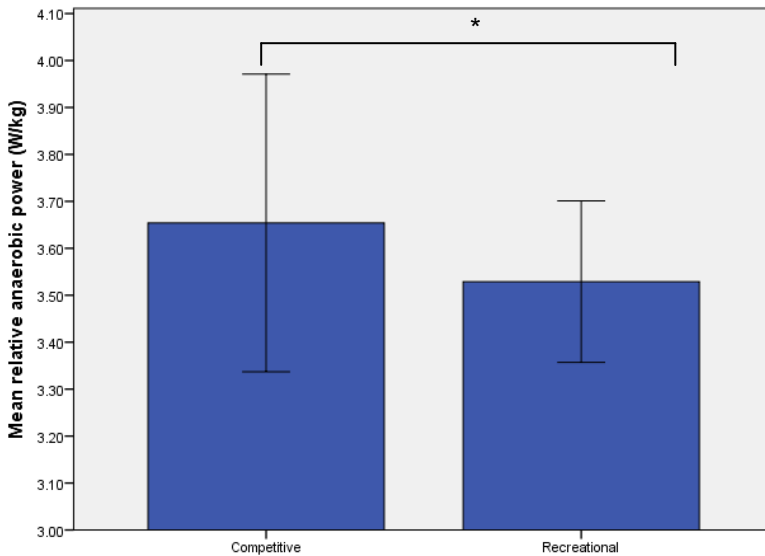


Figure 31: Mean relative (W/kg) Anaerobic Scores for Competitive and Recreational Male Surfers

3.1.2.5. Discussion

The purpose of this study was to 1) to provide the aerobic and anaerobic profile for female and male competitive and recreational surfers and determine if differences exist between groups; 2) to provide the body composition of a competitive and recreational surfing cohort with the use of DEXA and 3) to determine if physiological testing could be used in a surf specific screen to assist in discriminating performance. Findings from the current study support our hypothesis that competitive surfers tested on a swim bench ergometer had significantly higher values for both oxygen consumption and anaerobic power. In contrast to our hypothesis body composition measured by DEXA did not significantly differ between competitive and recreational surfers tested in this study.

3.1.2.5.1. Aerobic Testing

Time motion analysis revealed that upper body aerobic paddling represents the largest component of surfing (Mendez-Villanueva & Bishop, 2005). The competitive group had significantly higher aerobic scores in comparison to the recreational group. These findings suggest that high levels of aerobic fitness are attributes associated with competitive surfers. This is logical when considering the activity requirements of a competitive heat and the

associated additional training. Farley et al. (2012a) reported that during a 20 minute competitive heat a surfer is required to participate in repeated high and low intensity paddling bouts (1 to 20 seconds) interspersed with short rest periods accumulating $54 \pm 6.3\%$ of the total heat time. This paddling requirement may foster a high capacity for oxygen uptake in order to allow for sufficient recovery between paddling bouts. High intensity interval training has previously been shown to increase maximal oxygen consumption (Helgerud et al., 2007). Given that paddling is characterised by a series of short sprints it may be these demands of competitive surfing which cause increases in maximal oxygen consumption. Competitive surfers are also involved in additional training that is designed to replicate paddling bouts in heats. This is commonly achieved using interval type training methods (Secomb, 2012).

The findings from the current study have both similarities and inconsistencies with previous surf specific research (see Table 38). The competitive VO_{2peak} scores are similar to research conducted (Farley et al., 2012a; Loveless & Minahan, 2010a); however the recreational scores appear to be consistently lower than previous research conducted by Loveless and Minahan (2010a) and Meir et al. (1991). All of the aforementioned studies had sample sizes of less than 10, thus limiting the ability to compare their results with the current study and generalise their results to a recreational and competitive surfing cohorts. The current study revealed significant differences in VO_{2peak} scores between recreational and competitive surfers. Previous research (Loveless & Minahan, 2010a; Méndez-Villanueva et al., 2005) had not identified this, however both of these studies had sample sizes of less than 10 surfers in each group; once again limiting the ability to generalise the results to a surfing population. It could also be questioned whether there were true representations of competitive and recreational groups.

To our knowledge only one study has presented female aerobic fitness profiles in a surfing cohort. Lowdon and Pateman (1980) conducted submaximal bicycle ergometer testing to estimate maximal oxygen consumption (VO_{2max}) in 14 competitive female surfers. The VO_{2max} scores (62.2 ± 8.2 ml/kg/min) were double the current study VO_{2peak} scores; however our study conducted peak oxygen consumption testing in a surf specific position which utilizes smaller muscle groups and hence the reduction in VO_{2peak} scores. As would be expected competitive females exhibited significantly ($p < .001$) higher VO_{2peak} scores compared to their recreational counterparts. These findings are limited to the current study and results should not be generalised to female surfing cohorts, as further research needs larger sample sizes. It should also be noted that reliability was not assessed for the aerobic testing. Due to the nature of this VO_{2peak} testing repeated assessment was not feasible.

3.1.2.5.2. Anaerobic Testing

As previously mentioned 60% of paddling bouts were 1 to 20 seconds long, highlighting the importance of short intense paddling (Farley et al., 2012b). This activity requirement utilizes the anaerobic energy system and hence the need to attempt to replicate this activity on a swim bench. This study revealed significantly higher anaerobic scores in competitive surfers compared to recreational surfers (see Table 38). This is an important attribute to a competitive surfer as it assists in the ability to catch waves and gain a position advantage over their competitors during a heat. It may also allow for fast entry into a wave optimizing the execution of manoeuvres (Sheppard et al., 2012). It needs to be highlighted that competitive surfers commonly take part in additional training to further develop this energy system; therefore higher anaerobic scores in the competitive group may be due to both the activity requirements of surfing in heats and additional training. Nevertheless, this information adds to the physiological profile of a competitive and recreational surfer.

Only two published studies have conducted anaerobic testing in a surfing cohort using upper limb ergometers (Farley et al., 2012a; Loveless & Minahan, 2010b). Our results are slightly higher than the study conducted by Farley et al. (2012a); however a kayak ergometer was used which differs to the swim bench ergometer used in the current study. Loveless and Minahan (2010b) using the exact equipment, revealed slightly higher values for the competitive surfers (348 ± 78 W) compared with the results of the current study (303.93 ± 57.99 W). This inconsistency remains puzzling considering that the average weight for the study by Loveless and Minahan (2010b) was 61.1 ± 9.2 kg compared to the current study's average weight of 77.83 ± 6.62 kg. The current study revealed a significant correlation ($r = .83$; $p < .001$) between lean muscle mass and peak power output; therefore it would be expected that the heavier competitive group would produce greater peak power output scores. It needs to be noted that Loveless and Minahan (2010b) conducted six trials over two days to determine the mean power output of 348 ± 78 . It could be postulated that a learning effect occurred with subjects becoming more proficient at the motor pattern required and the demands of the test over the six trials.

Table 38: Aerobic and Anaerobic Profiles of Male Competitive and Recreational Surfers

	Study	Subjects	Testing mode	VO2 peak (ml/kg/min)	Peak aerobic power (W)	Absolute peak anaerobic power (W)	Relative anaerobic power(W/kg)
Competitive surfers	(Farley et al., 2012a)	n = 8; 20.6 ± 6.6 years	Modified kayak ergometer	44 ± 8.3	158 ± 20.7	205 ± 54.2 (n = 20)	2.83 ± 0.66
	(Loveless & Minahan, 2010a)	n = 8; 18 ± 1 years	Swim bench ergometer	39.5 ± 3.1	199 ± 45	348 ± 78 (n = 11)	-
	(Méndez-Villanueva et al., 2005)	European level (n = 7; 25.6 ± 3.4 years)	Modified kayak ergometer	50.0 ± 4.7	154 ± 37	-	-
		Regional level (n = 6, 26.5 ± 3.6 years)	Modified kayak ergometer	47.9 ± 6.3	118 ± 27	-	-
Recreational surfers	(Loveless & Minahan, 2010a)	n = 8; 18 ± 2 years	Swim bench ergometer	37.8 ± 4.5	199 ± 24	-	-
	(Meir et al., 1991)	n = 6; 21.2 ± 2.8 years	Swim bench	54.2 ± 10.2	-	-	-

Vales are presented as the mean and standard deviation (M ± SD)

3.1.2.5.3. Body Composition

This study was the first to utilize DEXA to determine body composition with the variable of interest being percent body fat. Results revealed competitive male and female surfers have low to moderate levels of body fat ranging from 17-26%. This is not surprising as surfers are not purely endurance athletes who tend to reveal lower body fat levels ranging from 8-13% through the use of DEXA (Nana et al., 2014). The results of the current study are similar to previous research, which has used skinfold assessment to estimate body fat with values ranging from 10.5-22% for competitive male and female surfers (Felder et al., 1998; Lowdon, 1980; Mendez-Villanueva & Bishop, 2005). It could be postulated that low body fat values do not represent a

real advantage from a performance perspective. It has also been suggested that higher body fat levels are possibly an adaptation to surfing in colder waters as additional body fat provides greater insulation (Lowdon & Pateman, 1980; Mendez-Villanueva & Bishop, 2005). Once again, this information adds to building the profile for recreational and competitive surfers using DEXA.

3.1.2.5.4. Performance Screening

The final aim of this study was to determine if physiological testing could be used to discriminate in performance. Significant differences were revealed between competitive and recreational surfers indicating the ability of the aerobic and anaerobic testing to discriminate between groups. However, when analysing the competitive cohort separately, no associations were detected. Whereby a surfers ranking and key performance variables (peak and relative power and VO_{2peak}) were not correlated. This finding suggested that although high anaerobic and aerobic levels are associated with competitive surfers they do not assist in determining their individual level of performance. This is logical as a surfer is ranked according to their ability of actually riding a wave (performing critical manoeuvres) which was not assessed with these physiological tests. Therefore, although paddling assessment is crucial to undertake, it does not assist in discriminating the level of performance in a competitive cohort. It should however be noted that the standard deviations for key performance variables (VO_{2peak} , peak and relative power output) were all minimal indicating most results were closely related. Perhaps a test which resulted in a wide spread data set may have illustrated a stronger correlation. However, a single study conducted by (Farley et al., 2012a) has previously shown a correlation between season rank and anaerobic scores achieved during a 10-second paddle sprint.

Interestingly a correlational analysis revealed significant ($p < .05$) associations between arm span, lean muscle mass and key performance variables (VO_{2peak} , peak and relative power output). These results may suggest that those surfers with longer arms and greater lean muscle mass produced higher VO_{2peak} and anaerobic scores. Correlations between arm span and VO_{2peak} scores are commonly reported in swimming studies (Jurimae et al., 2007; Moura et al., 2014). There were no differences in height between the competitive and recreational group; however, arm span significantly differed as with the ratio of arm span divided by height, known as “Ape Index”. This finding is unique as it raises the question as to whether significant increases in arm span in the competitive group are a result of a physical predisposition.

Finally, this is the first surf specific study to analyse symmetry of power output during aerobic and anaerobic paddling tests. No statistical difference was found between the dominant and non-dominant arms for power outputs during either test. This finding is novel in itself as it provides information that symmetry of power output is needed during paddling. This opens up several practical applications; where-by surfers suffering shoulder injuries could use swim bench ergometers for corrective and feedback purposes. It could also be used as a screening tool to identify asymmetry or even for rehabilitative purposes.

3.1.2.6. Conclusion

To our knowledge, this study is the largest comparative surf specific study to date that has effectively presented the physiological profile of male and female competitive and recreational surfers. Key performance variables (VO_{2peak} , peak and relative power output) are significantly higher in competitive surfers indicating this is both an adaptation and requirement in this cohort. Interestingly no significant correlation was identified between key performance variables and ranking in the competitive cohort. This suggests tests which replicate wave-riding components, may be more appropriate to discriminate in the level of performance. Arm span and ape index were the anthropometric measurements that were significantly greater in the competitive group; whether this is a result of training effect or a physical predisposition is yet to be determine. This comprehensive study adds to the physiological and physical profile of a recreational and competitive surfer. This battery of physiological tests could be used as a screening tool to identify an athlete's weaknesses or strengths. Coaches and clinicians could then select appropriate training regimes to address weaknesses.

There is also potential for this research within the surfing industry. Prior to the arrangement of sponsoring deals, a surfer could undergo physiological screening to provide the company with additional information. This concept is not foreign to many mainstream sports and may be of benefit to both the athlete and the company providing the sponsorship. Whereby, the surfer is provided with a profile of his or her strengths and weakness along with strategies to address their weaknesses. The company is provided with additional information regarding the state of the athlete from a physiological point of view.

CHAPTER 4: DISCUSSION

4.0.1. Preface

This final chapter provides a summary of the key findings in relation to each individual chapter and corresponding Aim. This chapter also presents study limitations, practical applications and recommendations for future research. Finally, the thesis conclusions are presented.

4.1. SUMMARY OF KEY FINDINGS

Chapter 1 was centred on injury epidemiology with the specific aim, “To provide current epidemiological data regarding injury incidence, type and mechanism for acute and chronic injuries in recreational and competitive surfers”. Chapter 1 included an extensive literature review conducted around surf specific injury epidemiology and the methodology used to obtain this data. The review identified a need to obtain new data, which addressed injury stage (acute and chronic), mechanism of injury and use appropriate injury definitions. It was also apparent that data collection occurring in hospital or emergency departments commonly reported high frequencies of skin lacerations primarily due to direct trauma by the surfboard. It was questionable whether previous research conducted in emergency or hospital environments accurately represented acute surfing injuries. Surfers with acute musculoskeletal conditions may present to other practitioners (physiotherapists) or not receive treatment at all. The review therefore recommended the need to utilize an online survey which would allow national access. Using the recommendations from the reviewed literature, Study 1 was implemented and the results presented in two papers.

The online survey identified up to date information on the injury incidence, location, types and causes of acute and chronic surfing related injuries. The incidence proportion was determined to be 0.38 CI (0.35 – 0.41); therefore 1 in every 3 surfers would experience an acute injury in a 12 month period; this increased to 1 in every 2 if the surfer was involved in competition or aerial surfing. Shoulder, ankle, head/face had the highest frequencies of acute injuries accounting for 16.4%, 14.6%, 13.3% respectively. These findings were in agreement with previous survey based research in a surfing population (Meir et al., 2012; Nathanson et al., 2002).

The predominant acute injury type was of muscular origin (30.3%), followed by joint (27.7%) and skin (18.9%). These findings revealed higher proportions of injuries of muscular origin compared to previous survey based research (Meir et al., 2012; Nathanson et al., 2002; Taylor et al., 2004). The growth of injuries of muscular origin in the current study may be due to the change in board design and the changes in surfing style. Where-by, lighter boards have allowed aggressive and radical manoeuvres to be performed thus placing increased stresses on the musculoskeletal system. The survey also revealed that surfers completing aerial manoeuvres were at significantly greater risk of sustaining acute injuries, which were commonly located to the lower limb. This was the first study to identify aerial manoeuvres as a risk factor for acute injuries; therefore, no comparisons with previous research can be made.

The second paper presented data around chronic injuries that were primarily of musculoskeletal origin (92%). This finding was a contrast to previous research investigating chronic injury, which reported nearly half of chronic injuries to be of non-musculoskeletal origin (Nathanson et al., 2002; Taylor et al., 2004). As previously mentioned, lighter boards and the addition of aerial manoeuvres may contribute to increased stresses on the musculoskeletal system. The locations with the highest frequencies of chronic injury were the lower back, shoulder and knee regions representing 23.2%, 22.4%, 12.1% respectively. Previous research investigating chronic injury revealed similar findings concerning injury location (Nathanson et al., 2002; Taylor et al., 2004).

It was apparent following Study 1 that musculoskeletal conditions were the prevailing form of injury and further understanding of musculoskeletal assessment was needed in a surfing cohort. Chapter 2 therefore addressed surf specific screening methods. When reviewing the surf specific literature minimal emphasis was placed on musculoskeletal assessment in comparison to physiological assessment. Therefore, Chapter 2 aimed “To design a surf specific screen incorporating reliable and specific methods for a surfing population”. A general review around screening methods provided a platform for the musculoskeletal component of the surf specific screen. However, two specific literature reviews identified the need to develop new surf specific clinical assessment techniques for both the thoracic and shoulder region. Therefore, Study 2 was conducted with the results presented in two reliability papers.

The first paper from Study 2 set out to evaluate the reliability of a new method to assess thoracic mobility in the sagittal plane and an existing method known as the lumbar locked method to assess thoracic rotation. Results revealed excellent ICC scores (.95 - .99) for the sagittal and rotation methods. The second paper from Study 2 evaluated the reliability of a new method to assess ROM of shoulder IR and ER in a prone position. This study also assessed the same movements in supine to investigate whether a difference existed between positions. The results revealed that ER was significantly ($p < .05$) greater in prone when compared with supine regardless of the device used (HALO or inclinometer). It was therefore determined to utilize a prone position to assess shoulder IR and ER as this is considered a surf specific position compared with the commonly used supine position.

Following on from Chapter 2, which identified the assessment techniques to be used in the surf specific screen; Chapter 3 presented Study3. This study implemented the Surf Specific Screen in recreational and competitive surfers. The results of Study 3 were presented in two papers

centred on the musculoskeletal profile and the physiological profile of both recreational and competitive surfers. This Chapter addressed the Aim “To provide a comprehensive musculoskeletal and physiological profile of a recreational and competitive surfer”.

The first paper from Study 3 was centred on the musculoskeletal profile and presented baseline values for body composition, ROM and isometric strength for competitive and recreational surfers. Male competitive surfers had significantly greater ($p < .05$) ROM in key regions (thoracic rotation, lumbar extension, hip internal rotation and ankle dorsiflexion) compared to recreational males. No differences existed between shoulder and cervical ROM or thoracic ROM in the sagittal plane. These findings promote two questions as to why these differences may exist. Firstly, “Are these differences in ROM due to the activity demands in competitive surfing?” Video-graphic evidence shows that during manoeuvres performed on a wave excessive ROM occurs at several joints. It could be hypothesised that the repetitive action of surfing manoeuvres results in muscular and joint adaptations when compared to recreational surfers who are not performing these manoeuvres to the same degree of difficulty. The second question is, “Are these differences present due to land based conditioning?” Study 1 identified that competitive surfers spend significantly ($p < .001$) more time completing dry land training, which may involve joint and muscular mobility work.

Regardless of the rationale behind the ROM differences in competitive and recreational surfers, the question which needs to be asked is, “What do these differences mean from a performance and injury prevention perspective?” Chapter 1 revealed that competitive surfers sustain significantly more injuries than recreational surfers do. So despite having greater ROM they sustain more injuries. This finding needs to be viewed with caution as competitive surfers attempt difficult manoeuvres and spend more time in the water. Longitudinal studies are needed to determine the significance of these findings from a performance and injury perspective. Where-by, surf specific screening is conducted prior to sustaining an injury. This may provide information regarding the “optimal ROM” needed in competitive and recreational surfing cohorts and any other risk factors for injury.

Concerning isometric strength testing in the trunk, no statistical difference existed between both competitive and recreational males for any of the tests (Beiring Sorenson and Side Hold Test). When comparing these results to sedentary people, the surfing cohorts appear to have greater hold times. However when comparing the current study results to water based athletes such as

stand up paddle boarders (Schram et al., 2014) they appear similar. These results indicate that the activity requirement of surfing may potentially develop the trunk musculature.

Throughout Study 3, symmetry between limbs and legs was assessed through muscle mass (DEXA), ROM, strength and during paddling assessment. Interestingly no asymmetry existed for all forms of testing apart from shoulder assessment in the recreational cohort. Here recreational surfers had significantly ($p < .05$) greater internal rotator isometric strength in their dominant arm and significantly ($p < .05$) less IR ROM in their dominant arm compared to their non-dominant arm. This finding has previously been supported by Kubo et al. (2001) who linked an increase in muscle strength with a reduction in ROM at the site. The rationale for asymmetry between arms in the recreational group could be due to the lack of dry land training or the amount of actual surfing compared to the competitive cohort. It is also possible that competitive surfers would participate in corrective exercises if asymmetries were present.

To our knowledge, this is the first study to present this type of data on symmetry in a surfing cohort. It is apparent that symmetry is a common finding among a surfing cohort and it should be suggested that surfers who have identified asymmetry should have the appropriate corrective exercises implemented; especially as asymmetry has been linked with injury (Costill et al., 1991).

The second paper from Study 3 presented the physiological profile for both male and female surfing cohorts. Significant differences were evident between competitive and recreational surfers in all three areas of testing. Anthropometric measures revealed that competitive surfers had significantly ($p < .05$) greater arm span despite no difference in height compared to recreational surfers. Arm span was also significantly ($p < .05$) correlated with VO_{2peak} and anaerobic power. This finding is unique as it raises the question as to whether significant increases in arm span in the competitive group a result of training effect or a physical predisposition. Secondly, significantly ($p < .05$) higher VO_{2peak} and anaerobic scores were found in competitive surfers when compared to recreational surfers. This may suggest that high levels of aerobic fitness are attributes associated with competitive surfers. This suggestion is logical when considering the activity requirements of a competitive heat and the associated additional training. To our knowledge this is the first study to reveal competitive surfers have significantly higher aerobic and anaerobic scores.

Both the aerobic and anaerobic forms of testing were able to discriminate between groups, however neither test was able to discriminate the level of performance within the competitive

group, highlighting the limitation of this form of testing. This finding is reasonable as a surfer is ranked and scored according to their ability of actually riding a wave (performing critical manoeuvres); which was not assessed with the current physiological tests.

4.1.1. Study Limitations

- The general limitation of the Study 1 was the retrospective nature of the survey. Retrospectively recalling an injury has been shown to result in participants failing to remember specific details of the injury (Jenkins et al., 2002). Unfortunately, this method of data collection was the only feasible option for the time frame available. Another limitation of Study 1 was the inability to record multiple injuries at the same anatomical site. Future collection methods need to be prospective in nature to address the aforementioned limitations. Developing close relationships with board rider clubs will enable implementation of injury recording methods. Currently Surfing Australia High Performance Centre (HPC) and Bond University are working closely together. Athletes are assessed and information regarding training volumes, surfing frequency and acute and chronic injuries being recorded. Due to the small cohort of high profile athletes at the HPC, data collection will need to be conducted longitudinally to reveal trends and significance.
- Study 2 revealed several limitations regarding the development of a new clinical method to assess sagittal movement in the thoracic spine. Firstly, the method begins in a maximally flexed position and ends in maximal extension. It therefore does not provide a value for either extension or flexion but a combined value. A clinician is not provided with which direction is limited or excessive. A simple correction would be to obtain a starting measurement in a “neutral” position and then proceed to measure both flexion and extension. The limitation of taking a reading in “neutral” is it adds time to the assessment method and it is questionable as to whether or not the subject is truly in their “neutral” position. For example if the subjects slouches or sits upright the amount of flexion or extension maybe under or over represented.
- The thoracic rotation method assessed in Study 2 was highly reliable and requiring only an inclinometer. However, it is questionable whether or not this is the most surf specific position. A sitting position may be more specific in a surfing cohort; unfortunately, the

methods using a sitting position used a goniometer. During pilot testing, it was extremely difficult to maintain the goniometer on the subject while they rotated and therefore this method was not selected. Further research will look to design a new clinical method utilizing a sitting position.

- The findings from Study 3, “Musculoskeletal profile”, are unable to determine the “optimal” ROM or strength values as injuries were recorded retrospectively. A study design, which is longitudinal with prospective injury data collection methods, may provide conclusions regarding optimal ROM and strength values from an injury prevention and performance perspective. This may provide information regarding surfers who may be at risk of sustaining an injury due to ROM and or strength limitations. Unfortunately, a longitudinal design was not possible within the timeframes of this thesis.
- The physiological assessment tests were unable to discriminate between the skill levels in the competitive group. A surfer is ranked and scored according to their ability of actually riding a wave; therefore, perhaps a test that assesses lower limb muscle power in surf specific position may be more appropriate in discriminating the level of performance in a competitive group.

4.1.2. Practical Applications

The practical applications of this research extend into the injury management and prevention, performance and screening areas.

- Aerialist and competitive surfers are identified as high risk for acute injury. Coaches should ensure appropriate conditioning regimes are implemented in these cohorts.
- Prior to this thesis, there was minimal information on baseline values for musculoskeletal and physiological assessment within a recreational and competitive cohort. Coaches and clinicians can now utilise this information to assist with designing appropriate training regimes. The results of this study can be used as a guideline to compare with the surfer they are currently assessing and or treating.

- By implementing this comprehensive surf specific screen in a surfing cohort individualised strengths and weaknesses are identified. Coaches and clinicians can then implement appropriate corrective exercises. This may aid in preventing further or future injuries and potentially enhance performance.
- Coaches who want to identify a surfer's weaknesses or strengths from a paddling perspective can utilize the testing procedures outlined in this thesis and compare their results to the current findings.
- There is also potential for this research within the surfing industry. Prior to the arrangement of sponsoring deals, a surfer could undergo a surf specific screen to provide the company with additional information. This concept is used in many mainstream sports. This may be of benefit to both the athlete and the company providing the sponsorship. Whereby, the surfer is provided with a profile of his or her strengths and weakness along with strategies to address their weaknesses. The company is provided with additional information regarding the state of the athlete from a musculoskeletal and physiological point of view. This could potentially assist in determining duration of contracts etc.

4.1.3. Recommendations for Future Research

From an academic point of view a plethora of studies are possible that will build on the current information this thesis has provided. Research in the sport of surfing remains limited and several studies are proposed below. A continuation of the current studies will help to establish normative values in surfing cohorts. Longitudinal studies will determine the significance of the findings within this thesis from a performance and injury prevention perspective.

This research has resulted in several collaborations between various academic and industry partners. Currently California State University (San Marcos) and Surfing Australia are collaborating to continue further research outlined below.

Further research studies include:

- Development of prospective methods to record injuries sustained during surfing
- A continuation of musculoskeletal and physiological profiling in conjunction with prospective methods to record injury
- Further development and refinement of musculoskeletal methods
 - Developing a clinically useful thoracic rotation method in a sitting position
 - Assessing shoulder IR and ER isometric strength in a mid-range position
 - The incorporation of lower limb strength and power tests
- Further development and refinement of physiological assessment methods
 - Maximal oxygen uptake testing using a swim flume
- Biomechanical analysis
 - Quantifying paddling technique
 - Biomechanical analysis of surfers with shoulder injuries
 - Vertical jump testing with the use of a force plate

4.2. CONCLUSION

This thesis was centred on the recreational and competitive sport of surfing. It involved three distinct areas; injury epidemiology, surf specific screening and profiling. Each of these areas was effectively addressed across the first three chapters. A summary of the major conclusions are presented below in Table 39.

Table 39: Summary of Thesis Conclusions

Injury Epidemiology
The shoulder, ankle, head and face are the key regions where acute injuries occur in surfers and the lower back, shoulder and knee are the key regions where chronic injuries occur in surfers. The results of this research have identified an increase in muscular and joint injuries along with providing insight into the mechanisms of injury related to specific body regions. Key risk factors for injury include; competitive status, an ability to perform aerials and increased participation levels. This knowledge may aid in reducing the occurrence of injury through screening awareness and the use of sports specific strength training and conditioning.
Surf Specific Screening
A comprehensive surf specific screen has been developed to be utilized in both competitive and recreational surfers. New thoracic and shoulder assessment techniques were developed and are highly reliable. It was identified that greater shoulder ER is achieved in prone compared to supine regardless of device. It would seem more logical to adopt this sport specific position when assessing shoulders of prone dominant athletes (surfing or swimming).
Profiling
The musculoskeletal and physiological profile of recreational and competitive surfers has been presented; adding to the limited research specific to surfing. Competitive surfers possess significantly greater arm span, ROM (thoracic rotation, hip internal rotation, lumbar extension, ankle dorsiflexion) and aerobic and anaerobic scores compared to recreational surfers. This may be both an adaptation and requirement for competitive surfers. Symmetry between limbs and legs was assessed through muscle mass (DEXA), ROM, strength and during paddling assessment. Interestingly no asymmetry existed for all forms of testing apart from shoulder

assessment in the recreational cohort. It is apparent that symmetry is a common finding among a surfing cohort and it is suggested that surfers who have identified asymmetry should have the appropriate corrective exercises implemented. Longitudinal studies are needed to determine the significance of these findings from an injury prevention perspective. Where-by, musculoskeletal profiling is conducted prior to sustaining an injury. This may provide information regarding “optimal scores” needed in competitive and recreational surfing cohorts to reduce the occurrence of injury.

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APPENDICES

Appendix 1: Ethics Approval

18 October 2012

Professor Wayne Hing and James Furness
Faculty of Health Sciences and Medicine
Bond University

Dear Wayne and James

Protocol No: RO 1540
Project Title: Self-reported acute and chronic injuries in recreational and professional surfers

I am pleased to confirm that your project was reviewed under the Full review procedure of Bond University's Human Research Ethics Committee and you have been granted approval to proceed.

As a reminder, BUHREC's role is to monitor research projects until completion. The Committee requires, as a condition of approval, that all investigations be carried out in accordance with the National Health and Medical Research Council's (NHMRC) National Statement on Ethical Conduct in Research Involving Humans and Supplementary Notes. Specifically, approval is dependent upon your compliance, as the researcher, with the requirements set out in the National Statement as well as the research protocol and listed in the Declaration which you have signed.

Please be aware that the approval is given subject to the protocol of the study being undertaken as described in your application with amendments, where appropriate. As you may be aware the Ethics Committee is required to annually report on the progress of research it has approved. We would greatly appreciate if you could advise us when you have completed data collection and when the study is completed.

Should you have any queries or experience any problems, please contact early in your research project: Telephone: (07) 559 53554, Facsimile: (07) 559 51120, Email: buhrec@bond.edu.au.

We wish you well with your research project.

Yours sincerely



**BOND
UNIVERSITY**
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**HUMAN RESEARCH
ETHICS COMMITTEE**

Research Ethics Committee
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AND BOND STAFF
0004-0001-0004

16 December 2013

Wayne Hing, James Furness, Mike Cimstein and Scott Johnstone
Faculty of Health Sciences and Medicine
Bond University

Dear Wayne, James, Mike and Scott,

Protocol No: R01610
Project Title: Musculoskeletal and Physiological profile of elite and recreational surfers: Injuries and sports specific screening

I am pleased to confirm that your project was reviewed under the Full review procedure of Bond University's Human Research Ethics Committee and you have been granted approval to proceed with the proviso that in due course, you will submit a revised Explanatory Statement and consent form for the Intervention study in phase II.

As a reminder, BUHREC's role is to monitor research projects until completion. The Committee requires, as a condition of approval, that all investigations be carried out in accordance with the National Health and Medical Research Council's (NHMRC) National Statement on Ethical Conduct in Research Involving Humans and Supplementary Notes. Specifically, approval is dependent upon your compliance, as the researcher, with the requirements set out in the National Statement as well as the research protocol and listed in the Declaration which you have signed.

Please be aware that the approval is given subject to the protocol of the study being undertaken as described in your application with amendments, where appropriate. As you may be aware the Ethics Committee is required to annually report on the progress of research it has approved. We would greatly appreciate if you could advise us when you have completed data collection and when the study is completed

Should you have any queries or experience any problems, please contact early in your research project: Telephone: (07) 559 53554, Facsimile: (07) 559 51120, Email: buhrec@bond.edu.au.

We wish you well with your research project.

Yours sincerely

Dr Mark Bahr
Chair



Participant Informed Consent Form

Project title: Musculoskeletal and Physiological profile of elite and recreational surfers. Injuries and sport specific screening

BUHREC Protocol Number: RO 1610

Explanatory Statement:

My name is James Furness and I am currently completing a PhD in the Water Based Research Unit at Bond University under the supervision of Professor Wayne Hing and Assistant Professor Mike Climstein.

I am conducting a research investigation into the sport of Surfing. I am specifically interested in the aerobic and anaerobic fitness, strength, flexibility and musculoskeletal health of elite and recreational surfers. Information gained here will assist in the development of injury prevention exercises for surfers of all ages and skill levels.

As part of this study, I will invite you to complete 1-2 hours of testing on site at Bond University's Institute of Health and Sport where various measures of physical capability including strength, endurance, flexibility, functional tests and fitness tests will be conducted. Fitness testing will be performed on a swim bench ergometer which is similar to a rowing machine; strength will be measured by timing your ability to maintain specific body postures. Flexibility will be measured through the use of basic physiotherapy tools. Functional tests will include lower extremity tasks; single knee bend, semi squat, lunge and hop lunge.

To assess your segmental body composition (percent fat and amount of lean muscle) we will conduct a dual energy X-ray absorptiometry (DXA) scan. This test is non-invasive where you will lay on your back on a padded medical exam table, the scan takes ~ 6 minutes and there is a small amount of radiation (less than the amount you would be exposed to on a flight from Gold Coast to Western Australia).

As the fitness tests are maximal tests, some minor muscular soreness may be felt post testing, this is a normal response to maximal exercise. You will be given the opportunity for an

adequate warm-up and cool-down. As this test is a maximal test it is important for you to realize to that you may stop when you wish because of feelings of fatigue or any other discomfort.

It is imperative you indicate to the testers if you have any history of coronary artery disease or other cardiovascular disorders and any current musculoskeletal conditions. There exists the possibility of suffering a bad physical reaction during the test. These may include abnormal blood pressure, fainting, and irregular, fast or slow heart rhythm and in rare instances heart attack, stroke or death. Every effort will be made to minimize these risks by the use of heart rate monitors, emergency equipment, tester training and preliminary evaluation prior to testing.

Participant Informed Consent

I agree to take part in the above Bond University research project. I have read the Explanatory Statement. I am willing to:

- Complete a test of maximal aerobic/anaerobic capacity
- Complete a dual energy X-ray absorptiometry exam for segmental body composition
- Perform tests of endurance by maintaining positions as long as I am able to.
- Under-go joint range of motion testing
- Complete four lower extremity tasks

I understand that my identity will be kept from being made public by anonymously labelling data and keeping all data in a secure location at all times.

I understand that my participation is voluntary; that I can choose not to participate in part or all of the project, and that I can withdraw freely at any stage of the project.

Should you have any complaints concerning the manner in which this research is being conducted please make contact with –

Bond University Human Research Ethics Committee,

c/o Bond University Office of Research Services.

Bond University, Gold Coast, 4229

Tel: +61 7 5595 4194 Fax: +61 7 5595 1120 Email: buhrec@bond.edu.au

Please tick the appropriate box

- ☐ I have no history of coronary artery disease or other cardiovascular disorders and any current musculoskeletal conditions.
- ☐ The information I provide can be used by other researchers as long as my name and contact information is removed before it is given to them.
- ☐ The information I provide cannot be used by other researchers without asking me first
- ☐ The information I provide cannot be used except for this project

Name:.....


Signature:..... Date:.....

Witness Name:.....

Signature:..... Date:.....

Appendix 2: Online Survey Example

This displays a 'mock' example of how the survey can be completed, this was done due to the size of the survey and the numerous ways a respondent can be directed.



Acute and Chronic Surfing Injuries

Background Information

Research surrounding surfing injuries dates back as far as 1977. As board design and the way we ride waves have changed so have the types of injuries. Therefore the purpose of this survey is to help identify the type and location of acute and chronic surfing injuries.

It is anticipated that data collected during this study will assist us to better understand surfing injuries. This survey is the first of three research studies. The following studies will involve physical and fitness assessments of surfers of all skill levels (recreational versus competitive). These studies will be conducted by the Principle Investigator (who is a qualified and practicing Physiotherapist) and will identify key areas that surfers need to address in order to prevent future injury. If you are interested in being a potential participant for the following studies please provide your contact details at the end of the survey. If you have no interest in future research simply leave this section of the survey blank. To continue please press "Next".

[Next](#)



Acute and Chronic Surfing Injuries

Explanatory and Consent Page

This survey consists of three major topics which include demographics (e.g., age, weight and skill level), acute and chronic injury. This survey will take approximately 10 minutes to complete.

The information you provide is purely on a voluntary basis. We do not anticipate any question to cause discomfort or embarrassment. However if this occurs and you no longer wish to continue the survey you may withdraw at any point with no repercussions and data already entered will be disposed of.

All personal data in this study will be treated with complete confidentiality and not made accessible to any person outside of the researchers working on this project. Data will be stored in a secure location at Bond University for a period of five years in accordance with the guidelines set out by the Bond University Human Research Ethics Committee.

If you wish to participate in this survey click "I agree and I am over 18 years old". Please note that by clicking "I agree and I am over 18 years old", you consent that you understand what is involved and are willing to answer the questions in this survey.

If you wish to participate in this survey and you are under the age of 18 years of age, please click "I agree and I am under 18 years old" and you will be required to have parental/guardian supervision whilst completing this survey.

If you do not wish to participate in the survey, simply click "No I disagree" and you will exit the survey.

Ethics approval: This project has been granted ethical approval from the Bond University Research Ethics Committee (BUHREC), Protocol number RO 1540.

Contact:

This research project has been conducted through Bond University's Faculty of Health Sciences and Medicine by James Furness, a Masters Student at Bond University. If you have any concerns or complaints concerning the manner in which this research is being conducted please use the contact below.

Bond University Human Research Ethics Committee,
c/o Bond University Office of Research Services,
Bond University, Gold Coast, 4229
Tel: 07 5595 4194 Fax: 07 5595 1120 Email: buhrec@bond.edu.au

*1. Do you consent

- ☒ Yes I agree and I am 18 years or older
☐ Yes I agree and I am under 18 years old
☐ No I disagree

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Acute and Chronic Surfing Injuries

Surf Participation

***2. Please indicate your gender**

- ☒ Male
☐ Female

***3. Please enter your age (please use numbers only)**

34

***4. Please select if you are natural or goofy footed (please note that if you are goofy footed your left foot is your back leg, if you are natural footed your right foot is your back leg)**

- ☐ Natural footed
☒ Goofy footed

***5. Please enter your weight in kilograms (between 30 and 200 kg, please use numbers only)**

76

***6. Please enter your height in centimeters (between 100 and 250 cm, please use numbers only)**

176

***7. Please select the type of surf board you predominantly use**

- ☒ Short Board
☐ Mini Mal
☐ Long Board (9 ft plus)

***8. Please select the number of years you have been surfing for**

- ☐ 1-5 years
☐ 5-10 years
☒ 10-15 years
☐ 15-20 years
☐ 20-25 years
☐ 25-30 years
☐ 30-35 years
☐ 35 years plus

***9. On average how many hours would you surf per week (between 0.5 and 40 hrs, please use numbers only)**

20

***10. How many weeks out of the year do you surf (between 1 and 52, please use numbers only)**

52

***11. Have you ever been diagnosed with a skin cancer by a qualified medical doctor (please note that this can only be determined if a small portion of the skin was cut out and tested for cancer cells)**

☐ Yes

☒ No

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Acute and Chronic Surfing Injuries

Surf ability

***12. Do you complete aerial manoeuvres on a regular basis (this means you can propel yourself and the board in the air and land back on the water standing on your board)**

☒ Yes

☐ No

***13. Have you ever taken part in any form of competitive surfing (for example Local board rider comps, Masters)**

☒ Yes

☐ No

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Next



Acute and Chronic Surfing Injuries

Surf Ability

14. Please select the forms of competitive surfing you currently or have previously been involved in

	I have previously been involved in	I am currently involved in
Local board rider competitions	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
State Junior Titles	<input type="checkbox"/>	<input type="checkbox"/>
Rip Curl Grom Search	<input type="checkbox"/>	<input type="checkbox"/>
Open State Titles	<input type="checkbox"/>	<input type="checkbox"/>
Australian Junior Surfing Titles	<input type="checkbox"/>	<input type="checkbox"/>
ASP World Pro Juniors	<input type="checkbox"/>	<input type="checkbox"/>
Open Australian Surf Masters Competition	<input type="checkbox"/>	<input type="checkbox"/>
Australian Surf Masters over 35, 40, 45, 50, 55 years	<input type="checkbox"/>	<input type="checkbox"/>
International Surfing Association (ISA) Open Division World Championship	<input type="checkbox"/>	<input type="checkbox"/>
ISA Junior World Championship	<input type="checkbox"/>	<input type="checkbox"/>
ISA Masters World Championship	<input type="checkbox"/>	<input type="checkbox"/>
Australian Surf Masters Single Fin	<input type="checkbox"/>	<input type="checkbox"/>
Australian Surf Masters Teams Event	<input type="checkbox"/>	<input type="checkbox"/>
World Qualifying Series (WQS)	<input type="checkbox"/>	<input type="checkbox"/>
World Championship Tour (WCT)	<input type="checkbox"/>	<input type="checkbox"/>
Other (please specify)	<input type="text"/>	

Prev

Next



Acute and Chronic Surfing Injuries

Acute Injuries

Acute injuries occur from a sudden impact or action while surfing. This normally involves a sudden sharp pain that you can relate to a specific event while surfing. Please note that a chronic injury is one that occurs over time and is different to acute injuries.

***15. Have you had an acute sudden injury while surfing over the past twelve months**

- ☒ Yes
☐ No

Prev

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Acute and Chronic Surfing Injuries

Acute Injury (upper half of the body)

This section may include a number of basic yes/no questions regarding each of the major joints in the upper half of the body.

***16. Did you suffer an acute injury due to surfing in the upper half of your body**

- ☐ Yes
☒ No

Prev

Next



Acute and Chronic Surfing Injuries

Acute Injury (lower half of the body)

This section may include a number of basic yes/no questions regarding the major regions of the lower body.

***17. Did you suffer an acute lower body injury while surfing in the past twelve months**

☒ Yes

☐ No

Prev

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Acute and Chronic Surfing Injuries

Acute Injury (lower back)

***18. Have you had an acute lower back injury that occurred from surfing in the past 12 months**

☐ Yes

☒ No

Prev

Next



Acute and Chronic Surfing Injuries

Acute Injury (knee)

*20. Have you had an acute knee injury that occurred from surfing in the last 12 months

☒ Yes

☐ No

Prev

Next



Acute and Chronic Surfing Injuries

Acute Injury (hip or groin)

*19. Have you had an acute hip or groin injury that occurred from surfing in the past 12 months

☐ Yes

☒ No

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Next



Acute and Chronic Surfing Injuries

Acute Injury (knee)

***21. Please select whether the acute knee injury occurred to your front or back leg**

- ☐ Front leg
☒ Back leg

22. Please select the type of acute injury that occurred to your knee (please select only one)

Type of injury	Skin Injury	Bone Injury	Joint or Ligament Injury	Muscle or Tendon	Marine Injury
Other (please specify)			Meniscus/cartilage injury		
<input type="text"/>					

23. What was the movement or event that occurred just before or contributed to the acute knee injury

- ☐ Struck by own board
☐ Struck by other surfers board
☐ Striking sea floor/ bottom
☐ Striking water
☐ Paddling
☐ Duck diving
☐ Take off
☐ Bottom turn
☒ Top turn
☐ Cut back
☐ Re-entry
☐ Floater
☐ Aerial
☐ Riding the face of the wave
☐ Tube riding

Other (please specify)

***24. Did this acute knee injury cause you to take any days off surfing**

- ☐ Yes
☒ No



Acute and Chronic Surfing Injuries

Acute Injury (knee)

***25. Did this acute knee injury cause you to take any days off work**

☐ Yes

☒ No

Prev

Next



Acute and Chronic Surfing Injuries

Acute Injury (knee)

26. How did you manage this acute knee injury (you may select more than one option)

☐ I didn't do anything

☒ I went to the GP

☒ I went to the Physiotherapist

☒ I managed it myself with rest, ice, compression

☐ I managed it myself with over the counter medication (pain killers, anti-inflammatories)

☐ I was seen by a Doctor in the hospital

☐ I had surgery

Other (e.g. Chiropractor)

***27. Did this acute knee injury require you to spend time in hospital**

☐ Yes

☒ No

Prev

Next



Acute and Chronic Surfing Injuries

Acute Injury (shin or calf)

***28. Have you had an acute shin or calf injury that occurred from surfing in the past twelve months**

☐ Yes

☒ No

Prev

Next



Acute and Chronic Surfing Injuries

Acute Injury (ankle or foot)

***29. Have you had an acute ankle or foot injury that occurred from surfing in the past 12 months**

☐ Yes

☒ No

Prev

Next



Acute and Chronic Surfing Injuries

Chronic Injury

Chronic injury is defined as a condition that occurs over a period of time with a gradual onset of symptoms. There may not be one specific event that caused the pain or discomfort. For an injury to be classified as chronic it needs to have been present for a period of 3 months or more. This may include injuries which flare up and down depending on the amount of surfing performed.

***30. Do you have any history of chronic injury**

- ☒ Yes
☐ No

Prev

Next



Acute and Chronic Surfing Injuries

Chronic Injury

***31. Has this chronic injury been caused or aggravated by surfing**

- ☒ yes
☐ No

Prev

Next



Acute and Chronic Surfing Injuries

Chronic injury (upper body region)

This section may involve basic yes/no questions regarding the major regions of the upper body.

***32. Do you currently or have you previously suffered from a chronic injury in the upper half of your body**

- ☒ Yes
☐ No

Prev

Next



Acute and Chronic Surfing Injuries

Chronic Injury (face, eyes, ears)

***33. Do you currently or have you previously suffered from a chronic injury to your face, ears or eyes**

- ☐ Yes
☒ No

Prev

Next



Acute and Chronic Surfing Injuries

Chronic Injury (neck)

*34. Do you currently or have you previously suffered from a chronic neck injury

☐ Yes

☒ No

Prev

Next



Acute and Chronic Surfing Injuries

Chronic Injury (shoulder)

*35. Do you currently or have you previously suffered from a chronic shoulder injury

☒ Yes

☐ No

Prev

Next



Acute and Chronic Surfing Injuries

Chronic Injury (shoulder)

***36. Have you been given a diagnosis from either a Physiotherapist or Doctor for your chronic shoulder injury**

- ☒ Yes
☐ No

37. Please select the type of chronic shoulder injury or use the text box below (you may select more than one option)

- ☐ Osteoarthritis/degeneration in the shoulder joint
☒ Rotator cuff injury
☐ Bursitis
☐ Unspecified shoulder pain

Other (please specify)

38. Please select what causes or aggravates this chronic shoulder injury or use the text box below

- ☒ Prolonged paddling
☐ High intensity paddling into waves
☐ Duck diving
☐ Pushing down on the surfboard to stand up
☐ Unknown

Other (please specify)

***39. Has this chronic shoulder injury caused you to take any days off surfing**

- ☐ Yes
☒ No

Prev

Next



Acute and Chronic Surfing Injuries

Chronic Injury (shoulder)

***40. Has this chronic injury caused you to take any days off work**

☐ Yes

☒ No

Prev

Next



Acute and Chronic Surfing Injuries

Chronic Injury (shoulder)

41. How have you managed this chronic shoulder injury (you may select more than one option)

☐ No management

☒ Self management with rest, ice, compression

☐ Self management with over the counter medications (pain killers and/or anti-inflammatories)

☐ Managed through a Doctor

☒ Physiotherapy

☐ I had surgery

Other (please specify)

***42. Has this chronic shoulder injury ever required you to stay in hospital**

☐ Yes

☒ No

Prev

Next



Acute and Chronic Surfing Injuries

Chronic Injury (elbow or forearm)

***43. Do you currently or have you previously suffered from a chronic elbow or forearm injury**

☐ Yes

☒ No

Prev

Next



Acute and Chronic Surfing Injuries

Chronic Injury (wrist or hand)

***44. Do you currently or have you previously suffered from a chronic wrist or hand injury**

☐ Yes

☒ No

Prev

Next



Acute and Chronic Surfing Injuries

Chronic Injury (ribs or sternum or the area between your shoulder blades)

***45. Do you currently or have you previously suffered from a chronic thoracic injury (note that this area includes the ribs or sternum or the area between the shoulder blades)**

☐ Yes

☒ No

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Next



Acute and Chronic Surfing Injuries

Chronic injury (lower half of the body)

This section may involve a number of basic yes/no questions regarding the major regions in the lower half of your body.

***46. Do you currently or have you previously suffered from a chronic injury in the lower half of your body (this includes your lower back region).**

☐ Yes

☒ No

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Next



Acute and Chronic Surfing Injuries

Future Research

Water Based Research Unit (Bond University)

Future studies with surfing will involve a physical screening and a fitness test on our land based surf equipment. This assessment will be done by a qualified Physiotherapist at no cost and will help identify areas of weakness or tightness that need attention in order to prevent injury. It will also provide a baseline measure of your surf fitness and general health. If you are interested in being a potential participant for future research please enter your contact details below. If you are not interested click "Next".

Please bear in mind that by providing your contact details you are consenting to potentially being contacted for future research. This means that the data you have given us in this survey will be identifiable, whereas if you don't give us your contact data it will remain anonymous. Please be assured that all data provided will be treated with complete confidentiality and not made accessible to any person outside the researchers working on this project.

Musculoskeletal screening and fitness testing will take place in the Gold Coast and ethical approval for that part of the project is pending. We envisage attaining ethical clearance in early 2013 (BUHREC Protocol number RO1610). It is intended that petrol vouchers will be allocated to participants for travel costs.

47. Please enter your contact details below or leave blank and click "next"

Name:
Email Address:
Phone Number:

Prev

Next

Appendix 3: Musculoskeletal Component of Surf Specific Screen

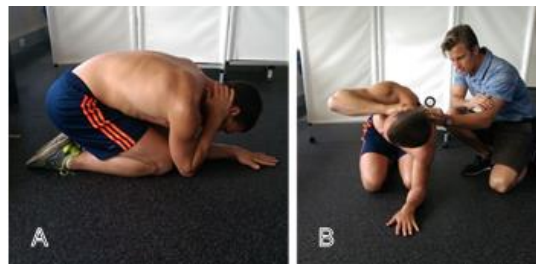
Cervical Rotation & Extension

Subjects sat in a supported chair with the lumbar and thoracic spines contacting the back of the chair, feet flat on the floor and arms positioned by side. This method was previously established by Audette et al. (2010).



Thoracic Rotation


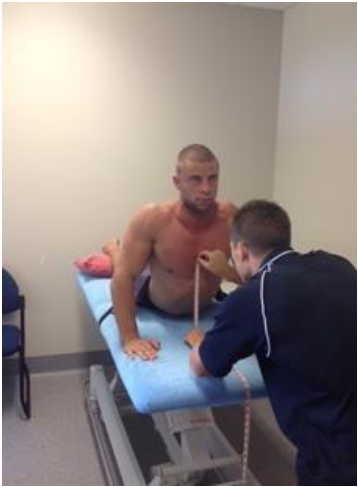
Subjects are placed in maximal hip and knee flexion with both elbows in contact with both knees on the ground. An inclinometer is placed over T1/2; the subject then rotates to one side ensuring the elbow on the opposite side stays in contact with the ground. This method was previously established by Johnson et al. (2012).



Static Thoracic Kyphosis

Two gravity dependent inclinometers are to be placed spinous processes of T1/T2 and T12/L1. Subjects are asked to adopt a natural posture by swinging their arms gently back and forth 3x and to flex and extend their neck 3x and stop in a position that felt natural and comfortable to them. The static kyphosis angle was calculated by



<p>adding each value on the inclinometers together. This method was adapted from Lewis and Valentine (2010).</p>	
<p>Thoracic mobility in the sagittal plane</p> <p>Subject is positioned in sitting and maximally flexes at the thoracic spine. A tape measure is placed from T1 to T12 and the distance is recorded. The subject then maximally extends and a tape measure is placed from T1 to T12 and the distance is recorded. Total thoracic mobility in the sagittal plane is the flexion value minus the extension value. The reliability of this method was investigated in Chapter 2.</p>	
<p>Lumbar extension in prone</p> <p>Positioned in a prone position with their hands directly under their shoulders. A belt is placed over the PSIS to secure the pelvic region. Subjects are instructed to extend their elbows and raise their trunk as far as possible. A tape measure is placed from the sternal notch to the contact surface and the distance is recorded. This method was previously established by Bandy and Reese (2004).</p>	

Lumbar Flexion in standing


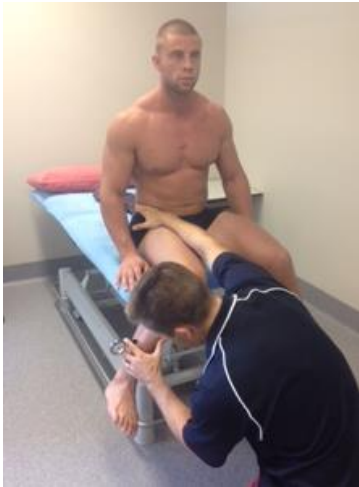
A line is drawn connecting both PSIS'. A mark is then made 15 cm superior. The subject then performs flexion by bending forwards keeping both knees straight with feet shoulder width apart. This method was previously established by Williams et al. (1993)



Active shoulder ER and IR in prone

Participants were positioned on in a prone position with the arm being assessed over the edge of the plinth. The arm was then taken into 90 degrees of abduction, the forearm flexed to 90 degrees and the wrist placed in neutral pronation/supination. The angle of abduction was confirmed through goniometric measurement. A rolled towel was placed under the upper arm so that the humerus was visually level with the acromion process. This ensured a neutral horizontal positioning of the arm. Subjects were instructed to rotate the arm. Light pressure was placed over the lateral epicondyle ensuring pure rotation. At the end of range, the



<p>inclinometer was placed on the anterior forearm adjacent to the radial styloid and the measurement taken.</p>	
<p>Active shoulder flexion</p> <p>Subjects were positioned in supine and asked to maximally flex at the shoulder joint. The inclinometer was placed 10 cm proximal to the lateral epicondyle on the medial aspect of the biceps. This method was adapted from Szomor et al. (2001).</p>	
<p>Hip IR and ER Active ROM</p> <p>For hip rotations, subjects were sitting with the hip and the knee flexed to 90°. A hand was then placed over the iliac crest to ensure no upward pelvic movement occurred. The subject was then instructed to rotate the hip. An inclinometer was placed 10cm proximal to the lateral aspect of the lateral malleolus. This method was adapted from (Malliaras et al., 2009; Nussbaumer et al., 2010)</p>	

Isometric side bridge

The lateral musculature is tested with the person lying in the full side-bridge position. Legs are extended, and the top foot is placed in front of the lower foot for support. Subjects support themselves on one elbow and on their feet while lifting their hips off the floor to create a straight line over their

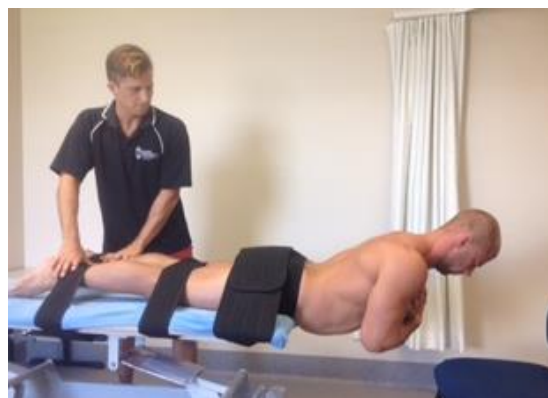
body length. The uninvolved arm is held across the chest with the hand placed on the opposite shoulder. Failure occurs when the person loses the straight-back posture and the hip returns to the ground, or the

participant request to stop, or they are unable to preserve form after one verbal warning. This method was previously established by McGill et al. (2010).



Biering-Sorenson

The back extensors are tested in the “Biering-Sorensen position” with the upper body cantilevered out over the end of a test bench and with the pelvis, knees, and hips secured. The upper limbs are held across the chest with the hands resting on the opposite shoulders. Failure occurs when the



upper body drops from the horizontal position, or the participant request to stop, or they are unable to preserve form after one verbal warning. This method was previously established by McGill et al. (2010)

ER and IR strength testing with the HHD

The subject is position in prone with the elbow and shoulder at 90 degrees. The HHD will be fixed to the ground. The participant will exert a maximal contraction against a stationary dynamometer with 5 seconds rest between the 3 contractions. To limit compensatory movements the participant was asked to maintain the contralateral shoulder on the ground during IR. During ER the subject was positioned in supine with the same shoulder position and the same procedure was replicated. For both movements the knees were to remain extended to limit bridging. This method was adapted from Dollings et al. (2012).



Single knee bend test

Starting from a standing position, individuals were instructed to have the contralateral knee flexed to approximately 80 degrees and to perform the single knee bend until they reached maximum dorsiflexion without lifting their heels and then return to upright standing. Two common visual rating methods (overall, segmental) were used. A dichotomous scale of yes or no for acceptable movement pattern was used. This method was previously established by Whatman et al. (2012)



Appendix 4: Surf Specific Screen Template

Name:

DOB:

Stance

Surfing Hx:

Competitive status, current and previous:

Hours per week/weeks per year:

Dry land training:

Injury Hx:

Acute

Chronic

Weight:

Height:

Resting BP:

Lipid: (NO FOOD 2 HOURS PRIOR)

TC (<5.5)

LDL (<2.5)

HDL (should be >than 1)

Tri (<1.5)



Aerobic fitness

Complete ESSA pre-screen (<2 risk factors); terminate test if; achieved max HR, RER above 1.15, O₂ uptake doesn't increase with work load or volitional exhaustion

VO2 Max:

VO2 max relative:

Peak RER:

Lactate (from inside little finger)

rest

0 min

1 minute

3 minutes

5 minutes

Anaerobic testing

Measurement Comments



(L) Ankle DF			(R) Ankle DF			Comments
Lumbar Flexion (>4.8cm)			Thoracic extension			
Thoracic Kyphosis (< 35)			(R) Thoracic rotn (>55)			
(L) Thoracic rotation			Cervical extension (78)			
Cervical Flexion (52)			(R) Cervical rotation (73)			
(L) Cervical rotn (73)			(R) Hip IR			
(L) Hip IR			(R) Hip ER			
(L) Hip ER			(R) Tibial IR			
(L) Tibial IR			(R) Tibial ER			
(L) Tibial ER			Shoulder IR supine (R)			
Shoulder ER supine (R)			Shoulder ER prone (R)			
Shoulder ER prone (L)			Shoulder IR prone (R)			
Shoulder IR prone (L)			Shoulder Flex (R)			
Shoulder Flex (L)						
Lumbar extension (>32cm)						



Lower extremity functional tests - visual rating sheet		
Please rate movement quality by filling in the sheet below for each of the four tests you view on the video clips.		
Please circle N (No) OR Y (Yes) for oscillation and each segment below (trunk, pelvis, knee, foot). For any YES rating please also grade by circling 1 (minor), 2 (moderate) or 3 (marked).		
Please also rate overall movement quality for each test.		
Trunk:	Moves out of neutral in frontal or transverse plane	[N] [Y; 1,2,3]
Pelvis 1:	Moves out of neutral in the frontal or transverse plane	[N] [Y; 1,2,3]
Pelvis 2:	Moves away from the midline	[N] [Y; 1,2,3]
Knee:	Patella moves out of line with 2nd toe	[N] [Y; 1,2,3]
Foot:	Moves into excessive pronation	[N] [Y; 1,2,3]
Oscillation:	Observable oscillation (movement to and from neutral)	[N] [Y; 1,2,3]
Overall movement quality:	Acceptable movement pattern	0
	Minor movement dysfunction	1
	Moderate movement dysfunction	2
	Marked movement dysfunction	3

Fig. 1. Visual rating sheet used in the study allowing both Segment and Overall ratings.

Appendix 5: Reliability Pilot Study

Measures	ICC (single measures)	ICC (average)	95% CI for single ICC	95% CI for mean ICC	SEM	SRD
Cervical Flexion (degrees)	0.936	0.978	0.787-0.988	0.917-0.996	2.31	6.40
Cervical Extension (degrees)	0.918	0.971	0.735-0.984	0.893-0.995	2.58	7.16
Cervical Rotation (degrees)	0.977	0.992	0.917-0.996	0.971-0.999	1.94	5.36
Thoracic Kyphosis (degrees)	0.962	0.987	0.868-0.993	0.952-0.998	1.70	4.72
Prone lumbar extension (cm)	0.939	0.979	0.796-0.988	0.921-0.996	1.44	3.99
Standing lumbar flexion (cm)	0.959	0.986	0.859-0.992	0.948-0.997	0.49	1.36
Hip IR (degrees)	0.856	0.947	0.573-0.971	0.801-0.990	1.99	5.51
Hip ER (degrees)	0.985	0.995	0.946-0.997	0.981-0.999	1.13	3.13
Ankle DF (cm)	0.962	0.980	0.796-0.993	0.886-0.997	0.61	1.70
Shoulder flexion (degrees)	0.956	0.985	0.800-0.995	0.923-0.998	1.46	4.04
Shoulder IR with HDD (Newtons)	0.912	0.969	0.717-0.983	0.884-0.994	15.72	43.56
Shoulder ER with HDD (Newtons)	0.801	0.924	0.456-0.958	0.715-0.986	9.95	27.58

Appendix 6: Additional Literature Review

Literature Review

The Reliability of Joint Range of Motion Testing at the Shoulder

Prepared by: Scott Johnstone (13240569)

Supervisor: Professor Wayne Hing, James Furness

Bond University

Doctor of Physiotherapy

INTRODUCTION

Physiotherapists commonly assess and treat musculoskeletal conditions around the shoulder. The glenohumeral joint is a multiaxial, ball and socket, synovial joint that depends primarily on the muscles and ligaments rather than bone for its support and stability (Magee 2008). In fact, shoulder pain is the most common musculoskeletal complaint seen in primary care practice (Lo 1990). Shoulder pathology has been

associated with limitations in glenohumeral rotation, particularly internal rotation (Wilk 2009).

Clinicians routinely evaluate change in a patient over time. Assessment of joint range of motion (ROM) is therefore critical in diagnosis of disorders, evaluation of treatment and quantifying the degree of change. It is therefore crucial for information to be available on the reliability of this ROM measurement. To be relevant to clinical

practice, this reliability must be strong with the same clinician performing assessment (intra-tester) as well as between clinicians when patient care is transferred (intra-tester).

There are an estimated 18 million surfers worldwide (Nathanson 2002) and 2.5 million recreational surfers within Australia. Surfing as a sport has grown and continues to grow dramatically. Until recently, there has been very little data encompassing the type and degree of injuries commonly occurring in surfers. A recent retrospective analysis study by Furness et al 2013 interviewed 1,348 recreational and competitive surfers. An injury rate of 2.44 injuries per 1000 hours surfing was identified. From these injuries, the shoulder had the largest distribution of acute significant injuries of any region. The repetitive nature of components involved in surfing may also predispose participants to more chronic injuries caused by muscle imbalance and associated shortening in the shoulder region (Mendez-Villanueva 2005). Currently no normative or comparative data exists relating muscle length in surfers to a normal population group. Reviewers hypothesize that differences would exist in a surfing population in regards to glenohumeral rotation. This hypothesis will be tested in research currently being undertaken.

This review aims to identify and confirm the most reliable methodology and anatomical position for testing of glenohumeral range of motion (flexion, internal rotation, external rotation). It also intends to identify any gaps in the current literature to direct future research.

METHOD

Identification and selection of studies

A search was conducted in November 2013 by one independent reviewer to identify published articles looking at the reliability of shoulder range of movement testing in various anatomical positions. Search terms included: Shoulder, range of motion and all synonyms for reliability. Studies applied to this literature review were identified by searching the following electronic databases: MEDLINE (Pubmed), Embase, CINAHL. In addition, reference lists of all papers retrieved were hand searched for relevant studies.

The titles and abstracts were screened by one reviewer. Studies were included if they met the inclusion criteria (Box 1). No restrictions were imposed on language or date of publication. When relevant, full text papers were retrieved. Studies using cadaver or animals were not considered for inclusion.

Box 1. Inclusion Criteria

Design
<ul style="list-style-type: none">Reliability studies involving repeated measures
Participants
<ul style="list-style-type: none">Symptomatic and Asymptomatic individuals
Measurement Performance
<ul style="list-style-type: none">Active and passive range of motion testing of the shoulderMovements: Flexion, External Rotation, Internal RotationUsed methods feasible for use in clinical practice (instruments, costs, training required)
Outcomes
<ul style="list-style-type: none">Measures of reliability (intra-tester and inter-tester)

Assessment of characteristics of the studies

Data was extracted on participants (number, age, clinical characteristics), raters (number, profession, training), measurements (anatomical movement performed, patient positioning, outcome reported), reliability.

Data was extracted by one independent reviewer who was not blinded to the journal, authors, or results obtained from studies.

No validated instrument is available for assessing methodological quality of reliability studies. Therefore a CASP list of criteria for quality of quantitative studies was used. These can be seen in Box 2.

Table 1. PICO Search Method

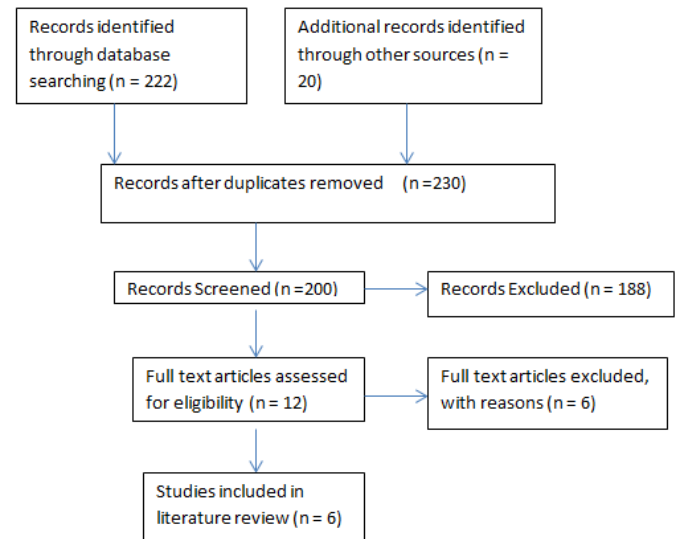
Patient Population	Adults
Intervention	Joint range of motion testing at the Shoulder Reliability Study
Comparison	Anatomical Position (Supine / Sitting / Side-lying)
Outcomes	Inter-rater and intra-rater reliability

Box 2. Criteria for Assessing Methodological Quality

1. Was there a clear statement of the aims of the research?
2. Is a qualitative methodology appropriate?
3. Was the research design appropriate to address the aims of the research?
4. Was the recruitment strategy appropriate to the aims of the research?
5. Were the data collected in a way that addressed the research issue?
6. Has the relationship between researcher and participants been adequately considered?
7. Have ethical issues been taken into consideration?
8. Was the data analysis sufficiently rigorous?
9. Is there a clear statement of findings?
10. How valuable is the research?

RESULTS

Flow of studies through the review



Searching MEDLINE yielded 222 citations using the above mentioned search terms. CINAHL (74) and EMBASE (22) found no additional relevant studies. Following screening, 6 published articles fulfilled all inclusion criteria.

Data Analysis

Data was analysed through examination of ICC values. ICC >0.75 indicated an acceptable level of reliability (Burdock et al 1963). The heterogeneity of the gathered studies meant it was not beneficial to summarise data through collating the levels of reliability

Description of studies

The included studies are summarized in Table 2. 4 studies investigated both the intra-rater and inter-rater reliability of shoulder range of movement (Riddle et al 1987, Hayes et al 2001, Muir et al 2007, Lunden et al 2010). 1 study investigated only inter-rater reliability (Wilke et al 2009) and the final study investigated only intra-

rater reliability (Kolber et al). 3 studies assessed shoulder range of motion passively (Riddle et al 1987, Wilke et al 2009, Lunden et al 2010) and 3 measured movement actively (Hayes et al 2001, Muir et al 2007, Kolber et al 2009).

Reliability by Anatomical Position

See table 3 below.

Table 2. Summary of Included Studies (n = 6)

Study	Participants	Raters	Joint Movement	Position	Method	Outcome Reported	Reliability Statistic
Riddle et al (1987)	n = 100 (2 groups of 50) Age = range 19 – 77 yr Condition = shoulder pathology referred to physio	n = 16 full time physiotherapists Training = N	Passive Shoulder <ul style="list-style-type: none"> - Flexion - Extension - Abduction 	Not standardized <ul style="list-style-type: none"> - Supine - Sidelying - Prone - Standing 	Goniometer <ul style="list-style-type: none"> - Large (10 inch and small (5 inch) 	ROM	ICC
Hayes et al (2001)	N = 8 Age = mean 66 yr (SD 5.7) Condition = shoulder pathology, post surgery	n = 4 Profession = 2 PT, 1 orthopaedic surgeon, 1 sports physician Training = Y	Active Shoulder <ul style="list-style-type: none"> - Flexion - Abduction - External rotation 	- Seated	Goniometry	ROM	ICC
Muir et al (2007)	n = 17 Age = Condition = normal and pathology	n = 2 Physiotherapists Training = Y	Active Shoulder <ul style="list-style-type: none"> - Abduction - Extension - Flexion - ER (0 deg abd and 90 deg abd) - IR at 90 deg abd 	- Standing - Supine (AROM and PROM)	Goniometry	ROM	ICC SEM
Wilke et al (2009)	n = 59 males (20 normal, 39 professional baseball players) age = 22 – 32 yr condition = normal	n = 2 Profession = 1 physiotherapist, 1 athletic trainer	Passive Shoulder <ul style="list-style-type: none"> - Internal Rotation (3 different methods) 	- Supine	Goniometry	ROM	ICC
Lunden et al (2010)	n = 70 age = 18 -75 Condition = normal and pathology	n = 2 Physiotherapists	Passive Shoulder <ul style="list-style-type: none"> - Internal Rotation 	- Supine - Sidelying	Goniometry	ROM	ICC
Kolber et al (2009)	n = 30 age = 23 – 42 Condition = normal	n = 1 Physiotherapist	Active Shoulder <ul style="list-style-type: none"> - Internal Rotation - External Rotation 	- Prone (IR) - Supine (ER)	Inclinometry	ROM	ICC

Table 3. Reliability by Anatomical Position

Position	Movement	Reliability
Supine	Flexion	Muir et al 2007 Intra-rater reliability AROM ICC = 0.92, PROM = 0.85. Inter-rater reliability AROM ICC = 0.76, PROM = 0.78
		Riddle et al 1987 Intra-tester reliability PROM ICC = 0.98 Inter-rater reliability PROM ICC = 0.89
	Abduction	Muir et al 2007 Intra-rater reliability AROM ICC = 0.87, PROM = 0.91 Inter-rater reliability AROM ICC = 0.80, PROM = 0.88
		Riddle et al 1987 Intra-rater reliability PROM ICC = 0.98 Inter-rater reliability PROM = 0.0.87
	Internal Rotation	Muir et al 2007 Intra-rater reliability AROM ICC = 0.87, PROM not included Inter-rater reliability AROM ICC = 0.62, PROM = not included
		Wilke et al 2009 3 methods of measuring internal rotation No stabilization <ul style="list-style-type: none"> ○ Intra-rater ICC = 0.48 ○ Inter-rater ICC = 0.47 ○ Mean ROM = 58 deg Scapular Stabilisation <ul style="list-style-type: none"> ○ Intra-rater ICC = 0.62 ○ Inter-rater ICC = 0.43 ○ Mean ROM = 46 deg Humeral Head Stabilisation <ul style="list-style-type: none"> ○ Intra-rater ICC = 0.51 ○ Inter-rater ICC = 0.45 ○ Mean ROM = 40 deg
		Kolber et al 2009 Inclinometry Intra-rater reliability ICC = 0.97

	External Rotation	<p>Muir et al 2007</p> <p>O° Abduction</p> <p>Intra-rater reliability AROM ICC = 0.89, PROM = 0.94</p> <p>Inter-rater reliability AROM ICC = 0.89, PROM = 0.86</p> <p>90° abduction</p> <p>Intra-rater reliability AROM ICC = 0.93, PROM = 0.89</p> <p>Inter-rater reliability AROM ICC = 0.95, PROM = 0.89</p>
		<p>Kolber et al 2009</p> <p>Inclinometry</p> <p>Measured at 90 deg abduction</p> <p>Intra-rater Reliability ICC = 0.97</p>
Side Lying	Internal Rotation	<p>Lunden et al 2010 was the only literature identified that assessed the reliability of shoulder ROM testing in a side lying position.</p> <p>Intra-rater and inter-rater reliability were reviewed with movements being performed passively by raters. Intra-rater reliability was excellent with ICC = 0.94 – 0.98). Inter-rater reliability was good to excellent with ICC = 0.88 – 0.96)</p>
Sitting	Flexion Abduction External Rotation	<p>The study by Hayes et al 2001 was the only identified study to assess the reliability of shoulder ROM testing in a seated position. Each of the 3 movements were measured using a goniometer and movements were performed actively. Inter-rater reliability was assessed using 4 different raters. Flexion ICC = 0.69, Abduction ICC = 0.69, External Rotation ICC = 0.64.</p> <p>Intra-rater reliability was also assessed with Flexion ICC = 0.53, Abduction ICC = 0.58, External Rotation ICC = 0.65</p>
Prone	Internal Rotation	<p>The study by Kolber et al in 2009 was the only literature found to look at reliability testing of the shoulder in a prone position (internal rotation). This was also the only study applied in this review which used an inclinometer to measure joint ROM. The position used was adopted from work by Clarkson 2005. In this prone position, compensatory scapula anterior tilt and protraction is limited by the table and towel roll (Clarkson 2005). Participants were asked to actively internally rotate the shoulder and inclinometer measurement was taken.</p> <p>Data shows excellent intra-rater reliability for internal rotation ICC = 0.987. Only one assessor was used.</p>

DISCUSSION

This literature review included 6 studies investigating intra-rater and inter-rater reliability of joint ROM testing of the shoulder. Studies using both active and passive movements were included. Results were collated into the anatomical position in which testing occurred for the particular study. An ICC value of >0.90 has been discussed by Portney and Watkins 1993 as a value recommended for making clinical decisions. Reviewers noted that reliability varied considerably with the method of assessment and also the anatomical position tested in. All study results included utilized instruments as this has been shown to be more reliable than vision alone (Van de Pol et al 2010)

In relation to anatomical position, far more studies were found to perform shoulder joint ROM testing in supine compared to the other positions (sitting, sidelying, prone). This was the case for all shoulder movements included (flexion, abduction, external rotation, internal rotation). Muir et al hypothesised reasons as to why variation in reliability values can arise. This includes the land marking during goniometer placement and also the lack of stabilization of the shoulder girdle to prevent compensatory scapulothoracic movements during rotation. Sitting positions may provide evaluation in a functional position however this also

induces muscular strength as a potential limiting factor.

Goniometric measurements of shoulder flexion and abduction in a supine position were found to have excellent inter-rater and intra-rater reliability (Muir et al 2007, Riddle et al 1987). When comparing active to passive range of motion there was greater variability found in passive range measurements (Muir et al 2007). This was however, the only paper to directly compare the two. This is likely due to variation in the amount of force used to attain full range and is an important consideration for clinical use especially when multiple clinicians are used. Active movements may therefore be preferable to passive movements in order to evaluate change in a patient's condition (Muir et al 2007). Shoulder internal rotation in supine demonstrated a greater variance in reliability between studies with Intra-rater reliability ICC 0.48 – 0.97 (Muir et al 2007, Wilke et al 2009, Kolber et al 2009). Such significant differences between studies is likely due to different methodology. Wilke et al 2009 compared 3 methods of measuring internal rotation and found the highest reliability to be with scapular stabilization method (ICC = 0.62). The most significant finding of this report was that significant differences in ROM were shown with the 3 methods of measuring internal rotation (no stabilization, scapula stabilization, humeral

head stabilization). Clinically this displays the importance of documenting the way in which joint ROM measures are assessed. Kolber et al 2009 displayed excellent intra-rater reliability (ICC 0.97) using inclinometry and protocol by Clarkson 2005. This study however only used one physiotherapist with 2 years' experience using an inclinometer and inter-rater reliability was not assessed. These factors make results difficult to compare with aforementioned literature.

With this variability demonstrated between raters in measuring internal rotation in supine, Lunden 2010 compared this position to side lying. This displayed a significantly greater intra-rater (excellent) and inter-rater reliability (good – excellent).

In a sitting position, Hayes et al 2001 assessed flexion, abduction and external rotation and found moderate reliability for each of these. Interestingly, inter-rater reliability was higher than intra-rater.

Reviewers of this paper have acknowledged the broad scope of areas attempted to be covered in this review. The limited data that was able to be retrieved makes it difficult to draw strong conclusions of reliability testing between movements and positions. A future review would be beneficial in which literature for a chosen movement is compared between positions. At the present time, there is insufficient literature for this to

be plausible for certain positions e.g. prone where only a single reliability study was found.

CONCLUSION

Evidence suggests that excellent inter-rater and intra-rater reliability exists for testing of shoulder flexion, abduction and external rotation in a supine position (Riddle et al 1987, Muir et al 2007). There is a large variability that exists between literature for Internal Rotation in a supine position. It appears that scapula stabilization is required to increase reliability of internal rotation assessment or that measurement in a side-lying position may be more reliable than supine (Lunden et al 2010). There is a significant lack of research into reliability testing of shoulder range of motion in a prone position. Future research could be directed at this position which is specific for many popular sports e.g. surfing.

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Appendix 7: Shoulder ROM Testing Positions and Device Placement

Prone Testing: Start Position

Participants were positioned on in a prone position with the arm being assessed over the edge of the plinth. The arm was then taken into 90 degrees of abduction, the forearm flexed to 90 degrees and the wrist placed in neutral pronation/supination (Clarkson, 2005). The angle of abduction was confirmed through goniometric measurement. A rolled towel was placed under the upper arm so that the humerus was visually level with the acromion process. This ensured a neutral horizontal positioning of the arm.

Device	Movement	Procedure
HALO	Internal Rotation	The HALO was placed on the mid-point of the lateral forearm. The mid-point was determined as half way between the ulnar styloid and the olecranon. Subjects were instructed to actively rotate the arm as far as possible. The device remained in this position until end of range where a reading was taken. The examiners free hand was lightly placed over the lateral epicondyle to limit any horizontal extension of the shoulder or extension of the elbow.
	External Rotation	The HALO was placed on the mid-point of the lateral forearm. Subjects were instructed to externally rotate the arm. From this prone position, examiners were able to visually see any thoracic extension or scapular retraction and correct this with verbal cueing.
Inclinometer	Internal Rotation	Subjects were instructed to internally rotate the arm. As per the HALO, light pressure was placed over the lateral epicondyle ensuring pure rotation. At the end of range, the inclinometer was placed on the anterior forearm adjacent to the radial styloid and the measurement taken

	External Rotation	Subjects were instructed to externally rotate the arm. The inclinometer was placed as per internal rotation and the measurement recorded. Examiners visually monitored for any thoracic extension or scapular retraction.
Supine Testing: <u>Start Position</u> Participants were positioned in a supine position with the olecranon at the edge of the plinth. All other aspects of the starting position were the same as the prone set up.		
HALO	Internal Rotation	The HALO was placed on the mid-point of the lateral forearm. The examiners other hand palpated the anterior humeral head and coracoid process. Active rotation was performed and subjects instructed to stop when scapular movement was felt.
	External Rotation	The Halo was placed on the mid-point of the lateral forearm. Subjects were instructed to externally rotate and the HALO remained on the forearm until end of range where the measurement was taken.
Inclinometer	Internal Rotation	The inclinometer was placed on the anterior forearm adjacent to the radial styloid. The movement was palpated as mentioned in HALO internal rotation
	External Rotation	Subjects were instructed to externally rotate the arm. At the end of range, the inclinometer was placed on the anterior forearm adjacent to the radial styloid and the measurement taken.

Appendix 8: Model Release Forms



Model Release Form

In signing this deed I irrevocably:

1. Consent to the University, its employees or agents photographing/filming me and using any image of me as the University sees fit in its absolute discretion to promote the University or any of the University's activities.
2. Acknowledge that all right, title and interest in or relating to any image of me taken by or on behalf of the University belongs to the University absolutely for its own use.
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Email Address:	darezzolo@hotmail.com
Mobile Telephone:	0427314888
Staff or Student Number:	13359300

Details:	
Purpose:	To provide sample pictures for Thesis/Paper
Location:	Bond University

Executed as a Deed

Signed, sealed and delivered by:

(Subject's signature)

Date:

29/05/2015



Model Release Form

In signing this deed I irrevocably:

1. Consent to the University, its employees or agents photographing/filming me and using any image of me as the University sees fit in its absolute discretion to promote the University or any of the University's activities.
2. Acknowledge that all right, title and interest in or relating to any image of me taken by or on behalf of the University belongs to the University absolutely for its own use.
3. Release the University from any claim by me, or on my behalf, arising out of the University's use of any photograph/video of me.

Released by:	
Full name:	Scott Johnstone
Email Address:	southjohnstone589@gmail.com
Mobile Telephone:	0431 204 373
Staff or Student Number:	NA

Details:	
Purpose:	To provide sample pictures for thesis/papers
Location:	Bond University

Executed as a Deed

Signed, sealed and delivered by:

(Subject's signature)

Date:

29/07/15